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fourth edition

prospecting in canada

A. H. Lang







Prospecting in Canada

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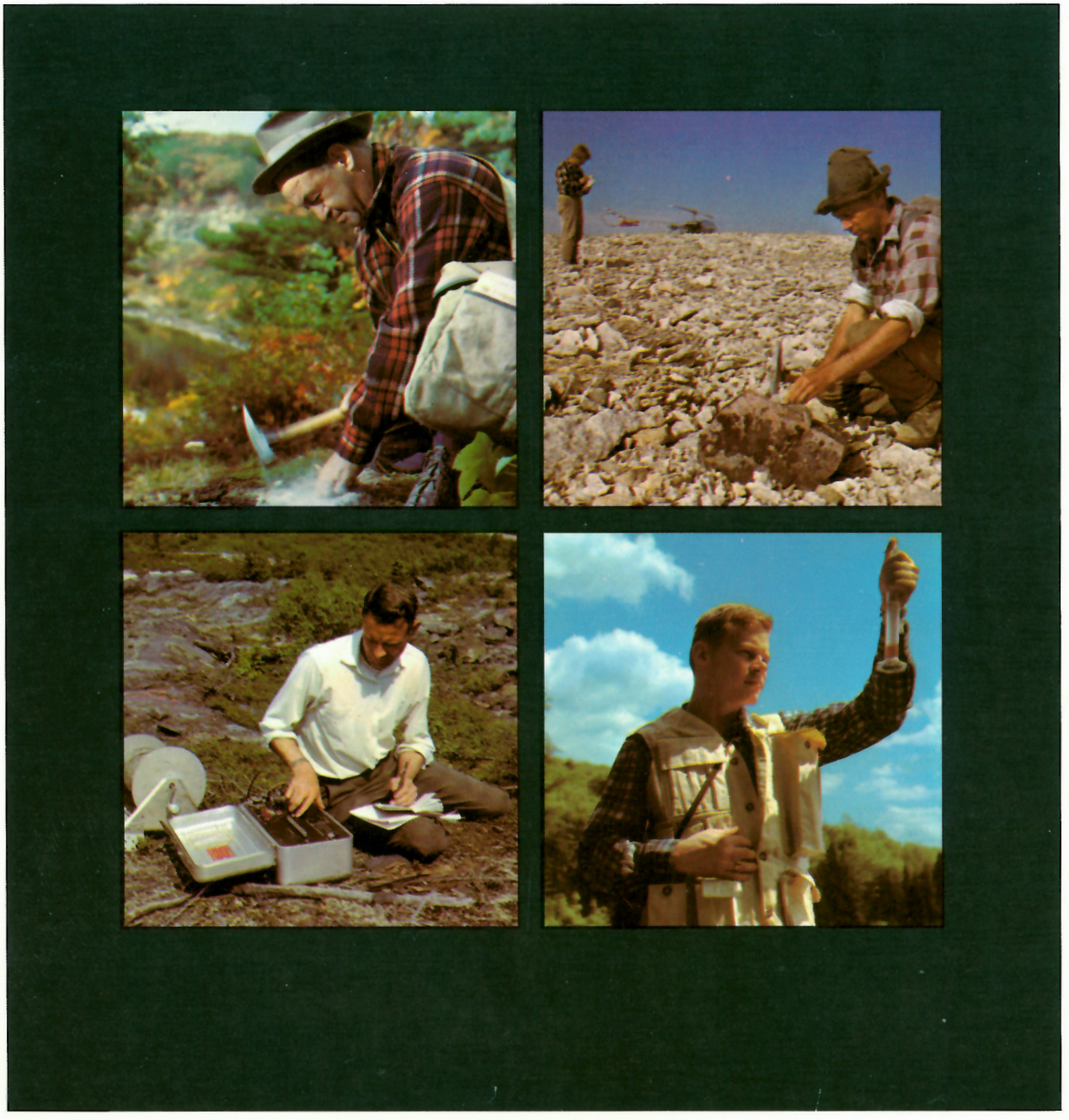

Plate 1. Conventional prospector, geologist, geophysicist, and geochemist — the four figures in modern prospecting.

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economic geology report no. 7

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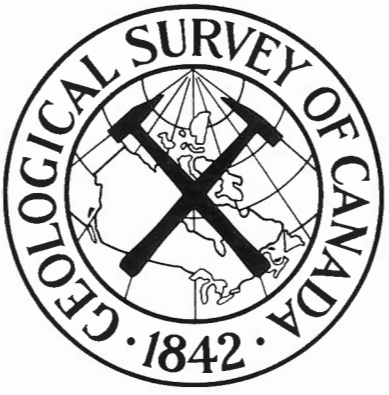
A. H. Lang



Geological Survey
of Canada

Department of
Energy, Mines and Resources
Ottawa

WIRTSCHAFTSGEOLOGISCHER BERICHT Nr. 7 — Prospektion in Kanada

Von A. H. Lang

Kapitel 1 — 9 und 14 — 17 bilden ein Lehrbuch für die Prospektion auf Erzgänge und Seifen in Kanada, und zwar für Kursusteilnehmer ebenso wie zum Selbststudium, Kapitel 10 — 13 enthalten kurze Einführungen in weiter fortentwickelte Methoden, hauptsächlich der Untertagearbeit, und sind mehr als allgemeine oder vorbereitende Lektüre als zur fachlichen Unterweisung gedacht.

ЭКОНОМИЧЕСКАЯ ГЕОЛОГИЯ, ОТЧЕТ № 7 — Разведочные работы в Канаде.

А. Г. Лэнг

Первые девять глав и главы от 14-й до 17-й включительно являются учебником поверхностной разведки жильных месторождений и россыпей в Канаде для лиц посещающих курсы по этому предмету или изучающих его самостоятельно. Остальные главы (10-я до 13-й включительно) — это краткие введения в сложные, главным образом подземные, методы предназначенные в основном для общего или предварительного ознаком—ления с предметом, а не для специализированного обучения.

PREFACE

The third edition of this useful publication proved so popular that three reprintings were required within ten years. However changes have been rapid in this subject and a new edition was obviously needed; this has been prepared by the author of the previous edition.

The book has the same general objectives as the earlier editions: to provide a textbook for prospectors on conventional surface prospecting and to include enough information on advanced prospecting to provide a sound introduction to these growing topics. Distribution data for the third edition indicate that, in addition to being used for adult education courses and independent study, the book is employed extensively as supplementary reading for university courses. It is also used by executive of mining companies for general information, by specialists in one kind of advanced prospecting to obtain up-to-date general knowledge on other methods, and by the general public. Many orders for the book come from other countries. These diverse uses have influenced the coverage in this edition, particularly a decision to include more information on advanced methods than is applicable to conventional prospectors; but obviously no single book can be considered a text on advanced prospecting.

The author, a long-time field geologist and later Chief of the Radioactive Resources and Mineral Deposits divisions of the Geological Survey, is familiar with his subject from his many contacts both with individual prospectors and with companies. It is hoped that this publication will continue to be of service to the Canadian mineral industry and will also serve to acquaint a broader public with a subject so vital to the economic well-being of Canada.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, 30 September, 1969

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Abstract

This book deals with prospecting in Canada in as much detail as is possible in one volume of medium size. It is a textbook on conventional prospecting but discusses advanced, sub-surface techniques only sufficiently to provide introductory, up-to-date information on what they involve. Petroleum is discussed briefly for general information only.

Prospecting is an important activity in Canada because mining forms a large sector of her economy, because of her large potential mineral areas, and because of the non-renewable nature of mineral resources. Canada has long been noted for her competent full-time and part-time conventional prospectors — men without advanced scientific or engineering training, many of whom attended adult-education classes in prospecting or studied alone. They searched for outcropping lodes and, in earlier times, for placer gold. Conventional prospecting is still significant and limited opportunities for it are expected to continue for many years. It has, however, been largely replaced by more advanced methods used mainly to search for deposits buried by overburden or barren rock. Analysis of histories of one hundred ore deposits found and brought into production in the 20 years from the end of World War II to 1966 indicated virtually that conventional prospecting was responsible for forty, geological studies entirely or mainly for thirty-two, and geophysics entirely or mainly for twenty-eight. The ratio of geophysical discoveries was higher in the latter part of the period. Geochemical studies assisted in several discoveries.

The writer's experience in geological work and in advising prospectors and companies was supplemented by advice from many qualified persons and by critical readings of many sections of the manuscript by authorities in the Department and outside it.

Résumé

Le présent volume traite de la prospection au Canada, d'une manière aussi détaillée que le permet un ouvrage de format moyen. Tout en restant un manuel de prospection classique, il offre néanmoins assez de données générales sur les nouvelles techniques souterraines pour initier le lecteur aux méthodes les plus récentes. Le domaine du pétrole n'est que brièvement abordé à titre d'information générale.

La prospection est un important domaine d'activité au Canada étant donné que l'industrie minière englobe un large secteur de son économie, que le pays possède un énorme potentiel de ressources minérales, et que ces dernières sont de nature non renouvelable. Depuis longtemps, le Canada est renommé pour la compétence de ses prospecteurs professionnels et amateurs, hommes de formation scientifique ou technique limitée ayant pour la plupart fréquenté des cours d'enseignement pour adultes ou étudié la prospection par eux-mêmes. Intéressés à l'origine par l'or placérien, ils ont ensuite dirigé leurs recherches sur les filons affleurants. La prospection classique occupe toujours une place importante, et les professionnels prévoient qu'elle offrira certaines possibilités durant de nombreuses années. Toutefois, des méthodes modernes l'ont largement remplacée, plus particulièrement dans la prospection de gisements recouverts de mort-terrain ou de roche stérile. L'analyse de l'origine de la découverte de 100 gîtes, exploités au cours des vingt années depuis la fin de la Seconde Guerre mondiale jusqu'en 1966, a révélé que la découverte de quarante d'entre eux provient de travaux de prospection classique, trente-deux provenaient entièrement ou principalement d'études géologiques, tandis que les travaux de géophysique étaient à l'origine des vingt-huit autres. Au cours de la seconde partie de cette période, les découvertes émanant d'études géophysiques offraient le pourcentage le plus élevé. Des études géochimiques étaient à l'origine de plusieurs découvertes.

Les consultations de divers spécialistes et la lecture critique d'experts de l'extérieur et du Ministère, de plusieurs sections du manuscrit, ont complété l'expérience de l'auteur en matière de travaux géologiques et de conseils aux prospecteurs et aux sociétés.

1

prospecting: past, present, and future

The search for mineral deposits that can be mined commercially has been an important Canadian activity for many years and is largely responsible for Canada's place among the world's principal mining countries. All mining is based on prospecting, the discovery of new deposits being essential both to replace those being mined and to provide for increasing and changing needs. Because the mineral industry is based on resources that cannot be renewed, new discoveries are particularly vital. This contrasts with the ways crops and livestock are reproduced fairly quickly and forests are re-grown slowly. Once ore is mined it is exhausted forever; some metals are recovered as scrap, but generally in quantities much smaller than those from new production. The geology of much Canadian territory is favourable in general ways for the discovery of new mineral deposits.

Prospecting has undergone many changes in personnel, in methods and equipment, and in the types of deposits sought. Most early prospectors were frontiersmen with little technical knowledge. Many had other interests besides prospecting and could turn to other ways of earning a living. After the most easily found deposits were discovered and as the means of gaining technical knowledge were improved a class of independent, well-qualified practical prospectors developed. The Canadian mineral industry owes much to these men, who were the envy of mining authorities in other countries. These prospectors searched for gold-bearing placers and for outcropping lodes, but possibilities for new placer discoveries have diminished and outcrops in accessible areas have been searched fairly thoroughly. In most areas rock exposures are not nearly as extensive as is bedrock covered by gravel, soil, or other such material. For these reasons, although this *conventional* type of prospecting is still significant particularly in the more remote parts of the country, emphasis has shifted to *advanced* kinds of prospecting which are used mainly to search for buried deposits. Advanced prospecting is generally undertaken by mining or 'exploration' companies and performed or supervised by scientists or engineers. Men of these callings, employed by government organizations, provide much of the basic information for both conventional and advanced prospecting.

This book has two main functions. One is to serve as a textbook on conventional prospecting for persons attending courses and for those following the subject entirely on their own. The other purpose is to provide brief, general coverage of all aspects of prospecting and the judging and testing of discoveries for readers who may be specialists in one type of prospecting, executives of mining companies, members of the general public, or persons thinking of engaging in some type of prospecting or a related field. Although opportunities for conventional prospecting are declining, those for the employment of fully trained scientists and engineers in advanced prospecting are increasing, and larger numbers of technicians of various kinds are employed on many of these projects. This book makes no pretence of being a text for any type of advanced prospecting, which would require several volumes, but it will provide an idea of what the various types involve and serve as an introduction to them. Deposits of oil, natural gas, and coal — and prospecting for them — are discussed only briefly because the search for oil and gas is a large subject beyond the scope of this book, and because additions to coal deposits already known are not now in much demand.

CANADA'S MINERAL INDUSTRY

Minerals, which have been a main part of the Canadian economy since pre-Confederation, were one of the chief factors in the great expansion in her industry and trade since World War II. Total mineral production in 1968 was valued at nearly $4¾ billion and was the highest ever. Minerals are now Canada's main exports. She is third among trading countries in diversification of exports and she ships metals, minerals, and their products to about eighty-five countries.

Besides metals and non-metallic minerals Canadian production includes oil, natural gas, coal, and structural materials such as stone and gravel, all of which are classed as parts of the mineral industry. Production of metals in 1968 was valued at nearly $2½ billion, fuels more than $1.3 billion, non-metallic minerals at nearly $459 million, and structural materials at more than $444 million. Ontario was the leading producer of metals, followed by Quebec and British Columbia.

In recent years Canada has been the world's leading supplier of nickel, zinc, and asbestos; the third in lead and gold; the fourth in iron and silver; and the fifth in copper. A few years ago Canada was the world's largest producer of uranium and that metal was her leader in value of production. She has the largest known reserves of uranium ore. Output of uranium declined because of temporary oversupply but is again increasing and is expected to rise further. During the last few years, however, copper has been the leading metal in terms of dollars, and asbestos has long been the leading non-metallic mineral.

A significant aspect of mining in Canada is that much, but by no means all, of it is carried on in parts of the country not well suited to agriculture or forestry and where

it is the sole or main activity. Prospecting and mining were main factors, from about 1860, in changing the economy of the western and northern colonies and territories from their base of fur trading to mining and other activities. New wealth created by mining, and the opinions of geologists that further mineral resources could be found, helped to unite these regions and to justify the establishing of roads, railways, and other aids to development. The bush-flying that revolutionized travel in the north was pioneered largely to serve prospecting. The mineral industry is bound to play an important role in the future; its magnitude will depend largely on how successfully prospecting can be applied and improved. Increased development will probably depend also on advances in methods of mining and treating ores, thus lowering costs and permitting use of lower-grade deposits, and on improvements in ways of evaluating and testing discoveries. In the past, less than one per cent of the mineral occurrences found have proved to be economically mineable. This is partly an inevitable circumstance owing to the nature of mineral deposits. It should not discourage prospecting because the industry has been adapted to it. Any improvements, however, that can be made in the accuracy of appraisals and in reducing the time and cost of appraising and testing would advance the industry and further the interests of prospectors, companies, and investors.

PROSPECTING IN THE PAST

Ancient Beginnings

In a general sense prospecting is among the oldest of human activities. Man apparently commenced using weapons and tools of wood and stone about 400,000 years ago and shaping them about 200,000 years later, roughly at the same time he began to use fire. Clay for making pottery was used by primitive peoples in many parts of the world. Gold nuggets and certain precious stones such as turquoise, seen in the beds of streams, early attracted the attention of man and were used as ornaments. Gold has been mined at least since 4,000 B.C. Copper found in the metallic state was more valuable to the ancients than gold because not only could it be shaped by hammering as could gold, but it was harder and could be made even harder by hammering. Salt was quarried at an early date and later was used as currency in some regions. The discovery of copper and bronze may be said to have given man mastery over his environment for the first time; the transformation brought about was so marked that the period is known as the Bronze (or Copper) Age in contrast to the very primitive Stone Age that preceded it. These terms denote a particular type of culture that existed for different periods in different parts of the world, rather than any fixed period of time; for example, the Eskimo have only recently emerged from the Stone Age, whereas certain New Guinea tribes discovered within the last few years are still in it. Man's discovery of the use of metals was one of the great turning points in his development, ranking with fire, the wheel, tillage of the soil, and the domestication of animals.

Tribes that spread from central Asia are believed to have brought the use of copper found in its 'native' or elemental state to the region east of the Mediterranean. Copper was used in the Aegean area from about 3,500 B.C. Later, men learned to smelt the more common metals from their ores. Long before the Christian era gold, silver, copper, iron, lead, tin, mercury, coal, and several varieties of precious and semi-precious stones were well known and widely used. Gold is fairly common in Egyptian tombs as early as 4,000 B.C. Miners had learned not only the art of washing gravels to recover minerals and ornamental stones, but also of mining solid rock in small shafts and tunnels by driving copper or iron wedges into crevices, and by lighting fires to heat rock faces, thus causing them to crack when cooled. Mining of copper in Cyprus has been dated at 2,500 to 3,000 B.C. In early times lumps of metal came to be used as currency, and the shaping of primitive coins followed. Although records of early prospecting lore are scanty, no doubt some men with aptitude specialized in prospecting and handed on observational knowledge without recording it. The Romans had a substantial mining industry, the remains and records of which show that some Roman prospectors had a little knowledge of mineralogy and geology. Early Chinese writers mention signs for gold, silver, copper, and tin, and for certain plants under which these were said to occur.

Despite these evidences of practical knowledge, most early prospecting seems to have been based on luck, useless folklore, and magic until after the Middle Ages. Then mining and related subjects including geology and the study of mineral deposits were advanced, particularly in the mining area of Bohemia and Saxony. There Agricola, a physician, wrote the first comprehensive and reliable account of these subjects, which is still read with interest. He shows a grasp of practical prospecting in these lines:

> Many persons hold the opinion that the metal industries are fortuitous and that the occupation is one of sordid toil, and altogether a kind of business requiring not so much skill as labour. But as for myself, when I reflect carefully upon its special points one by one, it appears to be far otherwise. For a miner must have the greatest skill in his work, that he may know first of all what mountain or hill, what valley or plain, can be prospected most profitably, or what he should leave alone; moreover, he must understand the veins, stringers and seams in the rocks. Then he must be thoroughly familiar with the many and varied species of earths, juices, gems, stones, marbles, rocks, metals, and compounds.

Mining and prospecting also owe much to the special aptitudes of the men who searched for and worked the tin–copper mines of Cornwall from the time of the Phoenicians to the present century, and who were in such demand that they took their skills to many parts of the world.

Ancient mines in various countries have been re-opened and worked successfully by modern methods. A company was formed in Canada recently to investigate such possibilities abroad.

Early Canadian Prospecting

The first Europeans to reach this continent and to leave written records found the natives using stone tools and weapons as well as a few of copper. Many signs of small-scale quarrying by natives have been found. Discovery of gold and other metals was one of the objectives of all the

early explorers. Cabot in 1497 noted that the natives of Newfoundland used copper. Cartier in 1535 obtained a copper knife said to be from the Saguenay country, and shipped to France some worthless stones he thought might be diamonds. Frobisher on his voyage in 1576 from England to Baffin Island and return brought back some rock rumoured to be gold ore, and succeeded in obtaining support for a larger expedition the following year, when he shipped a great quantity of rock that proved to be worthless, thereby not only marking the first recorded attempt at mining in Canada, but also exhibiting the tendency to over-optimism that has often accompanied the realistic activities of mining in this and all other countries. A few years later Champlain came to Canada and in his retinue brought a specialist in mining named "Master Simon" to investigate and try to develop mineral occurrences. He reported discoveries of iron and silver in 1604. After these beginnings, prospecting and a few small mining operations were advanced to some extent by the early French and English settlers in eastern Canada, but mining did not become an important factor, nor were prospectors numerous, until after the western gold rushes, when great stampedes of fortune seekers followed the discovery of placer gold in California in 1849, in the Cariboo in 1860, and in the Klondike in 1896.

Most men of the western Canadian rushes were adventurers inexperienced in prospecting and placer mining but many of them learned some lore from ones who had been in earlier rushes in California and Australia; others learned from Cornishmen who were among the stampeders, and probably also from Scottish coal miners who had been brought out by the Hudson's Bay Company and become interested in gold. As the best placer streams became staked or depleted, some men turned attention to gold–quartz veins in neighbouring hills and mountains, and later to rich lodes of silver and lead, thus beginning the first substantial 'hard-rock' prospecting in the West. Their numbers were increased by prospectors who migrated northward from lode-mining districts then being established in western United States. These events caused British Columbia to be the leading placer and lode mining province in the late 1800's and early 1900's. However, by that time substantial lode mines were also being worked in Ontario, the Eastern Townships, and Nova Scotia.

From these developments emerged a group now often referred to as the 'old-time prospectors'. The best of them had some practical knowledge of geology and mining, but this qualification was not then as important as it is today because the early prospectors were to a large extent travelling untrodden paths where the more obvious occurrences awaited discovery. Their outstanding characteristics were ability to travel and live under pioneer conditions, buoyant optimism, dogged perseverance, and open-handed hospitality. They were adventurers willing to undergo hardship for the opportunity to lead an independent and roving life and for the chance of 'striking it rich'. With backpacks, horses, and canoes they searched the streams, roamed the hills, and travelled the waterways until few large areas south of the Arctic had not been prospected, at least in a preliminary way. Their basic methods of prospecting were handed down from antiquity. These methods, which are still the basis of all 'direct' prospecting, consisted of developing a sharp eye for metallic minerals and the 'signs' that

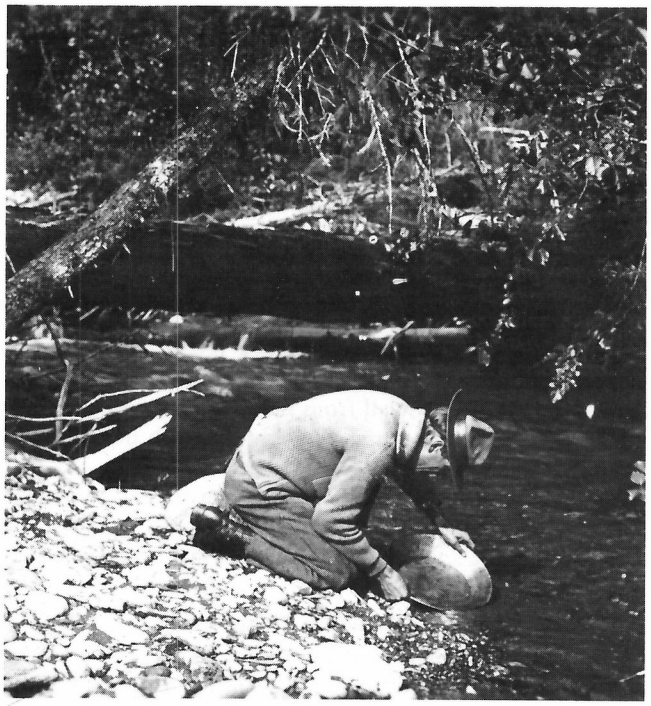

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Plate 2. Panning for placer gold.

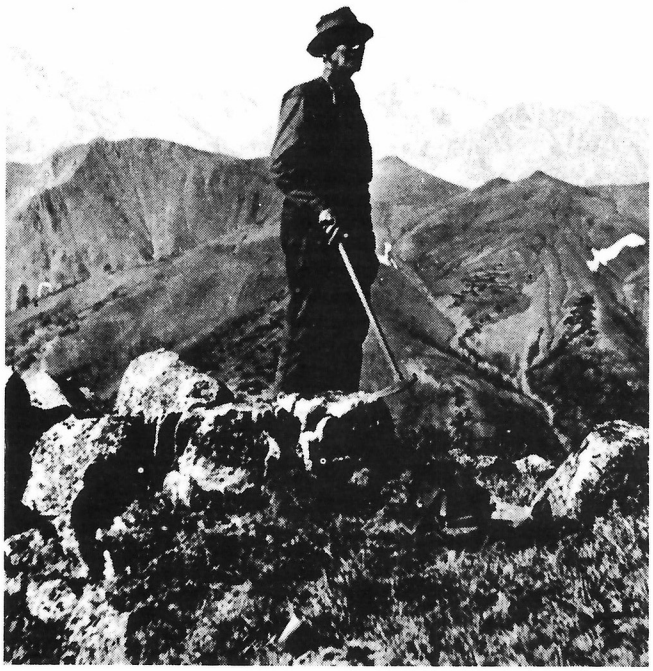

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Plate 3. An old-time hard-rock prospector (courtesy Macmillan).

often accompany them, tracing fragments of valuable minerals to their source, using the prospectors' pan to isolate grains of heavy metallic minerals in sand, gravel, or powdered rock, and scraping, pitting, and trenching to try to expose bedrock in promising places. They financed themselves by also doing some placer mining or by working for wages at various occupations for part of the time, or they formed a partnership with a 'grubstaker' who was generally a local business or professional man. Large and small mines that have since been exhausted, as well as some present producers, were found by some of these men but, inevitably, most of them found nothing or found prospects that did not warrant mining. The metals and minerals produced as a result of these activities were of great direct benefit to the country by adding to the supply of gold as a medium of exchange and a backing for bank-notes and in providing metals for Canadian use and for international trade. Even greater indirect benefits came from changing an economy based on furs to one based on mining, agriculture, and other industries, from opening up the country, from stimulating trade, and from providing men who later turned from prospecting and placer mining to other pursuits.

Late 19th and Early 20th Centuries

The activities outlined above continued into the present century. To some extent they continue today but in several ways they underwent gradual and important changes. The actual turn of the century was of no significance in this regard; the main cause of change was the building of the Canadian Pacific Railway in 1880–85. This provided easier access for prospectors and other mining pioneers, it lowered the cost of supplies and shipments of ores and their concentrates thus making deposits of lower grade worth seeking, and it provided training in blacksmithing, rock drilling, and blasting to men who turned to prospecting and mining when they tired of working on railroad gangs or when the line was finished.

With the growth of mining some men began to make prospecting for lodes their main or sole occupation and, although some such men remained at the educational level of their predecessors, others acquired skills in conventional prospecting comparable with those of other first-class tradesmen, and also showed initiative, resourcefulness, and bushcraft of a high order. The rise of this class coincided with the greater difficulty in finding deposits after the most obvious ones had been discovered, and with a rise in the number of persons who had completed secondary schooling.

Certain terms used in this publication are explained here to clarify later discussions. 'Conventional prospecting' is regarded as searching for placers and outcropping 'hard-rock' deposits by persons who are not scientists or engineers; it includes the use by such persons of fairly simple equipment, such as Geiger counters and mineral lamps, which is introductory to the more advanced kinds of prospecting mentioned later. The terms 'amateur' and 'professional' are avoided because they can be interpreted in different ways. 'Full-time' describes men who make prospecting their main calling, at least in summer, regardless of whether they prospect independently or for a grubstaker or company; 'part-time' describes persons having some experience and knowledge of the subject, and who prospect intermittently; 'novice' describes beginners. 'Prospecting' is used to include all kinds of searching (conventional or advanced) for mineral deposits that can be mined commercially. Some authorities use the term 'exploration' instead of advanced prospecting, but exploration is also applied in other ways; it is, therefore, largely avoided in this book for the sake of simplicity.

The more knowledgeable conventional prospectors learned by studying at home or by attending short courses established by various organizations in different provinces. The first was organized by the Ontario Department of Mines about 1895. Prospectors also learned from geologists encountered in the field or based at branch government offices, and prospectors employed or backed by companies commonly received some instruction from supervising engineers or geologists. Some men learned by acting as junior partners to experienced prospectors. The best conventional prospectors acquired a sound practical knowledge of geology and mineralogy and spent parts of the winters studying reports and maps at home or visiting libraries. They could make pace and compass surveys, and sketches of their traverses and discoveries, plot surveys with a Geiger counter or simple magnetic instruments, undertake preliminary testing and sampling of a discovery, and write an acceptable report of their activities. Some of these men were highly successful, and retired or became executives of large companies; others found lesser mines; and still others made a living by finding and 'turning over' prospects that failed to become productive, or by selling claims on which nothing was found but which were near a promising prospect, or by prospecting for companies on salary. Some part-time prospectors became proficient. These were men who studied independently or took courses, but who could leave their regular vocations only for part of the season, or who lived in an area favourable for prospecting and could search during spare time.

Along with serious novices there were always some who merely 'got the bug' and did not realize the enormous odds against the finding of a significant deposit by a person who knew little or nothing about prospecting. Their numbers greatly increased during booms, which ranged from local rushes to the widespread enthusiasm connected with the Klondike stampede in the late 1890's and the uranium boom about 1950. These booms were largely stimulated by glamorous publicity. Some persons apparently did not expect to find anything but went along for the adventure. Others literally thought nothing more was required than to pick gold off the ground or to buy a Geiger counter which they learned only to switch on and off.

Advanced prospecting by geologists and geophysicists was undertaken in limited ways long ago and began to be better established in the 1930's. Long before, geology had been recognized as important in providing basic data for choosing prospecting areas and guiding the search by conventional prospectors, and in evaluating prospects and



Plate 4
Modern conventional prospectors and geologists.

A. H. Lang

helping with the operation of mines, but employment of geologists in actual prospecting appears to have begun significantly about 1930. Also, during the Great Depression some geologists who could not find employment tried prospecting outcrops on their own, thus forming a transition between the conventional and advanced categories. Increase in the price of gold in 1934 caused many companies to seek gold deposits by trenching and drilling along possible projections of known gold deposits or other more general features. Geologists were used increasingly for choosing such sites and for studying the exposures obtained.

Geophysical instruments for measuring magnetism were used successfully in connection with searching and tracing iron deposits from about 1900. In the twenties these methods were improved and electrical and other means for detecting deposits of other metals were tested and used. The first, well-isolated, electrical discovery of an orebody covered by overburden appears to have been made at Buchans, Newfoundland, in 1926. Geophysical techniques were improved and used increasingly.

In general, prospecting declined during World War II. Although demands for staple metals such as copper and nickel increased, these metals were needed quickly and demands were filled mainly by larger production from existing mines or by bringing into production prospects that had been found previously. Also, persons who might have been prospecting were diverted to other activities. Another reason for the decline was that gold mining faced rising costs and low priorities. Prospecting for what were called 'strategic' minerals, such as manganese and tungsten, which were needed and in short supply, was increased by wartime demands. Searches for such deposits were made partly by conventional prospectors and partly by geologists, who were particularly successful in locating unsuspected sources of tungsten.

Some pertinent information on prospectors was obtained from a canvass of thirty-four experienced Canadian prospectors by F. R. Joubin in 1944.* Nine replied that they had taken courses in prospecting, and thirty-three stated that they studied the general subject of prospecting on their own initiative. All reported that they used reports and maps issued by the Geological Survey of Canada if available. Twenty-nine subscribed to a mining newspaper or magazine. Thirty-two believed in the systematic use of panning. The consensus was that at least eight to ten months of practical experience in field prospecting and bushcraft was necessary for a beginner to be at all qualified.

THE PERIOD SINCE WORLD WAR II

The end of World War II was a milestone in history of any kind, including that of prospecting and mining. During the post-war years the volume of Canadian mineral production rose greatly and the production value rose still more as a result of inflation. The decline of incentive to prospect for gold was offset by great interest in prospecting for uranium. Increased construction and the demands for

* Western Miner, vol. 17, no. 8, pp. 50–59, 1944.

automobiles and other goods, for Canadian use and for export, stimulated production of minerals and the search for new deposits. Mining for iron and molybdenum, which had previously been produced in Canada in relatively small quantities, was much stimulated. Although many persons resumed conventional prospecting or engaged in it for the first time, mining companies became increasingly involved in advanced prospecting, much of which was successful. Geophysical surveys were carried out extensively, geologists were employed in greater numbers, and geochemical surveys were shown to be more practical for Canadian conditions than was previously supposed. Many advanced projects comprised several advanced methods, and some included the employment of conventional prospectors. Some projects required expenditures of millions of dollars and extended over several years. Use of fixed-wing aircraft for preliminary geophysical surveys, air photography and transport was increased and helicopters were adapted for some of these purposes.

Although much prospecting was done in northern Canada during the post-war period, there was a marked increase of emphasis on old mining camps and generally favourable areas in more accessible parts of the country. This was caused partly by increased demands and prices for some metals and minerals, and partly because advanced methods of prospecting provided additional opportunities in areas where outcrops had been prospected and studied intensively long ago. As a result, several old mines were reopened, further study and testing of old prospects revealed orebodies, and completely new deposits were found. Significant changes in the 'frontiers' of Canadian prospecting and mining have thus taken place. The early frontier was westward, then during the period between the two World Wars it was extended northward, largely by bush-flying and conventional prospecting. Since then the 'frontier' has been largely downward, extending to deposits buried beneath the surface and beyond the scope of conventional prospecting. Mining is now possible to depths of 10,000 feet or more.

During this period the staking of claims reached new records in some provinces, but this does not reliably indicate whether claims were staked because of discoveries on them or for more speculative reasons, nor does it indicate the qualifications of the stakers or the methods of prospecting, if any were done. The best way of learning the present relative importance of the four main kinds of prospecting seems to be to determine as accurately as possible the ways in which producing mines and the most attractive prospects were discovered. This provides no indication of how many prospectors of various kinds were at work, but it indicates the relative importance of different methods. A study for the decade 1945–55 revealed that of 77 important mines brought into or nearing production during that period 31 were old mines or prospects, and that, of the remainder, 22 were conventional finds, 17 geological, and 7 geophysical. The writer compiled data for 178 mines brought into production or nearing production in 1956–66. The results, which are discussed in more detail in Chapter 10, are summarized as follows: 122 were reactivated former producers or old prospects brought into production because of further testing or changed conditions. Almost all of this group of 122 was attributable to conventional prospecting. Of the remaining 56, discovered since 1945, 18 were mainly or entirely conventional finds, 15 were geological, 20 were geophysical, and three were indeterminate because of incomplete reports. Fifteen were attributed to combinations of methods, including six geochemical 'supports'. The average time from discovery to production was about 30 years for the entire group of 178, and for the 56 more recent discoveries, 6½ years.

PROSPECTING IN THE NEAR FUTURE

The future of a subject like prospecting, which depends on many uncertain factors including luck, cannot be predicted as well as would be desirable. Forecasts are needed, however, by persons thinking of engaging in some form of prospecting or of backing prospectors, and by companies, government agencies, and educators. They will rely largely on their own judgments, but the following are the writer's present opinions.

In the world as a whole, more metals and energy were used in the 20th century than in all previous time. This trend will probably increase and cause greater demands for minerals, including fuels.

Conventional prospecting has been largely replaced by advanced methods but this does not necessarily imply that the conventional will soon die out. It might continue for some time at about its present rate or even increase slightly, but it will require skills at least comparable to those of the better conventional prospectors of today and previous years. This seems an obvious conclusion because outcrops in accessible places have already been prospected fairly thoroughly, and backers will require that men have good qualifications before sending them to remote places. Of course, there will be 'long' chances that a novice prospector will encounter a significant mineral occurrence in an overlooked outcrop or a new excavation or road-cut, but it stands to reason that the opportunities for prospecting outcrops will require adequate knowledge of the subject. These points indicate why this book had to be written at a fairly technical level.

Opportunities will probably continue for some time for persons to engage in the prospecting of outcrops as a part-time occupation or a hobby. Such persons will have to obtain proficiency by studying the subject and, if possible, taking a course, before expecting much consideration from experienced mining men. These persons know that there is a slight chance that a novice might find a valuable deposit, but they cannot devote much attention to persons who are not prepared to learn the fundamentals of prospecting. Naturally the opportunities for part-time prospecting in settled areas and vacation and tourist resorts are not as favourable as in more remote places. Better opportunities are available to persons who travel through, or live in, remote regions.

The extent to which conventional prospectors can use the simpler geophysical and geochemical methods seems impos-

sible to predict accurately at present. Some of these methods are now being taught in courses for prospectors but are not known to have yet been used widely by persons who attended such courses. Prospectors of the kind who mastered Geiger counters and other equipment of that level of complexity should be able to learn to make and plot surveys with equipment a little more complex, but they would probably find the results more difficult to interpret. For this reason the future of work of this kind may lie in having prospectors, individually or in small groups, who have suitable training and briefing on specific techniques, work for a company, perhaps on an 'incentive-bonus' agreement; the company would then have the results interpreted by its own staff or by a consultant.

The use and success of advanced, indirect methods seem bound to increase. By far the greater part of the bedrock surface in most areas is covered by overburden. Many mineral deposits must be obscured in this way, and many more must be completely covered by barren rock and yet be within the range of mining. Deposits hidden in these ways have been found by following geological hypotheses and by geophysical and geochemical methods, and by combinations of these. The known methods will probably become more efficient and entirely new ones may be developed by research. Most geophysical, geochemical, and geological projects require scientists or engineers who have advanced university training, together with larger numbers of technicians. The latter should have adequate specialized education supplemented by on-the-job training. A fairly typical establishment for advanced prospecting might include one or more scientists or engineers in charge of projects, several senior technicians, and a large number of junior technicians. Perhaps the best way for a person to enter the general occupation of prospecting without acquiring long university training will be to complete high school, preferably with courses in geology, chemistry, and physics. A technical high school would probably also provide useful courses in electronics and drafting. If possible this training should be supplemented by attendance at a technical college or its equivalent for six months to two years, during which time related summer employment could probably be obtained. In this way a prospecting supervisor or technician would sacrifice much of the independence and chance of great financial success held by earlier prospectors, but this would be offset by his being relieved of the problem of financing independent prospecting; also there might be opportunities for steady employment, as some advanced field work can be done in winter, when laboratory staffs are required. The natural desire for gain greater than salary might be provided for by some kind of bonus for exceptional discoveries. In these ways a person might progress in one or more organizations or, after gaining experience and training, might decide to try independently to be a conventional prospector or to use a geophysical or geochemical method, or he might be encouraged to obtain full university training in geology, geophysics, or geochemistry or their combinations.

Combinations of methods will probably be used increasingly, to allow for the possibility that deposits of more than one kind are present in the area being prospected, to confirm or rule out doubtful indications, and to narrow down preliminary indications — in other words, to bring them into better focus.

ABOUT THIS BOOK

Purpose and Scope

The first edition of *Prospecting in Canada* was published in 1930 and the second, issued in 1935, was virtually a reprinting with only a few words changed. These editions consisted of sections written by different officers of the Geological Survey, intended mainly for persons who wished to learn or review the subject by studying at home and to show how geological maps and reports could be better understood and used. Geophysical prospecting, then in early development, was discussed in a section designed mainly to indicate what was involved rather than to instruct. Thus some prospectors might learn to use the simpler magnetic instruments, and companies seeking geophysical help from a specialist might be able to judge the method most suited to a particular problem.

The second edition was soon exhausted and periodic suggestions were made that it be re-issued, but this was delayed because the treatment was too obsolete for reprinting and because there were too many other demands on the depleted staff during the depression and war years to permit the writing of another text.

Requests for a new edition particularly for use in adult-education courses in prospecting were so pressing by 1955 that the writer was asked to undertake it. He was aware of the impossibility of one person knowing the details of all the branches of modern prospecting, and of the difficulty of making scientific and technical subjects understandable to beginners without over-simplifying to the point of inaccuracy.

The third edition differed from the earlier ones in several ways. Requests indicated that a book was needed as a text for short courses in conventional prospecting and for persons studying alone, but it was clear that, although conventional prospecting still had an important place, more and more discoveries were being made by advanced methods and that these would have to be described to some extent in order to outline the subject of modern prospecting in as true form as possible in a single, elementary volume. It was decided, therefore, that the edition should cover conventional prospecting and matters related to it as thoroughly as possible and that enough information on the advanced methods would be included to give conventional prospectors an idea of what was involved in the methods beyond their scope. A booklet on geophysical methods issued by Canadian Exploration Geophysicists was incorporated, with modifications, by kind permission.

The third edition had unexpectedly large and varied distribution. Orders and comments indicate that in addition to the purposes foreseen, the volume is used by universities for supplementary reading in geological courses, by technical colleges, by company executives, by specialists in one branch of advanced prospecting who wish a general and

fairly up-to-date awareness of other aspects of the subject, and by investors and laymen. These uses are assumed to indicate that, despite the shortcomings of a single book that can only touch on many of the topics, a need exists for one that attempts to bring the whole subject into focus, to deal more thoroughly with conventional prospecting, and to discuss these matters in as non-technical language as possible.

The fourth edition follows the general pattern of the third but describes advanced methods more fully, in keeping with their growing uses and improved techniques. The chapters on advanced methods are, however, intended only as introductions to their subjects. About three-quarters of the book was rewritten to bring subjects up to date, and in an attempt to improve the presentation of several sections; the remainder has been touched up in many places. Many illustrations have been replaced or added.

Scheme of Presentation

The next few chapters deal with basic subjects that are fundamental to any kind of prospecting. Obviously, these cannot be treated fully in a book of this kind, but the information presented is considered sufficient to provide a sound foundation and to make the later chapters understandable. Chapters 6 to 8 contain practical advice on obtaining further instruction in prospecting and related subjects, on equipment and transport, and on the obtaining and uses of maps, reports, and air photographs.

Chapter 9 discusses conventional prospecting fairly fully, but it must be realized that this is a craft and that, like all crafts, many of its details cannot be written but must be learned by experience or passed on by a veteran to a disciple. This chapter is followed by a short general chapter on advanced prospecting, followed in turn by chapters on the three main specialties involved. These four 'advanced' chapters are not meant to provide instruction except in the use of certain fairly simple techniques involving instruments such as dip-needles and Geiger counters. They are, rather, meant to give a general awareness of the subjects and to introduce them to students intending to follow one of the specialties.

A chapter on the judging and testing of discoveries is required because independent prospectors have to make some judgments for themselves and commonly must do preliminary work to expose discoveries that they think warrant the attention of a mining company. More advanced appraisals and tests are discussed briefly, not to instruct those who undertake them but to give a general idea of what usually takes place. Chapter 15 consists of brief sections on the demands for various metals and minerals and on some considerations regarding prospecting for them, together with references to further information. These sections are intended to help persons to decide what to prospect for, and also to provide information on any particular element or mineral they identify or have reported from samples they send for identification or assaying.

A chapter on placer mining is included because gold placers are still worked in some parts of western Canada, and because it is not impossible that workable placers of other minerals might be found. The last chapter contains a short summary of laws and regulations on prospecting and mining, and discussions of ways to obtain financing for prospecting and to dispose of discoveries.

Appendices consist of tables and other information that may be useful to some readers but not to others, and which are therefore not included in the chapters. For convenient reference while reading other parts of the book, some appendices fold outward.

Terms that should especially be understood and remembered are printed in italics where first used or defined. Other terms that are not so essential to remember and words used in a special rather than their everyday sense are enclosed in quotation marks. Terms that are equivalent or almost equivalent to ones being used are enclosed in parentheses (brackets) because this may make other publications in which they are used more understandable. Chemical compositions of minerals are also enclosed in parentheses.

Sections or chapters are ended by lists of suggestions for additional reading if desired, and they in turn will indicate many more references. Suggested readings include inexpensive books, government reports, standard textbooks, and selections from the numerous articles available in technical and scientific periodicals. Booksellers should be able to obtain most of the books; prices are not listed because they are changeable. Some of the reports are out of print but they, and the articles, can be read in most university and some other libraries. Articles and books whose authors are not stated are listed alphabetically. Some listings include short comments by this writer.

A glossary of selected technical terms and some other words that may not be familiar to all readers is placed near the end of the book. Most of the definitions conform with those of standard geological and mining glossaries except that some are worded less technically, but the writer has used his own definitions or indicated a choice where one seemed desirable. Definitions of rocks and minerals provided in other parts of the book are not repeated in the glossary. The index lists only the principal places where words appear.

This book deals with several subjects that are too interdependent to be discussed only in one place. These are interwoven and developed in different parts of the book. This method causes some deliberate repetition which seems desirable to emphasize important points, to allow for the probability that some readers will not remember all that has gone before, and because some users will doubtless read only certain sections, which should be reasonably self-explanatory. In general, the more detailed discussions are towards the ends of sections or chapters.

Suggestions for Use

This book will probably be read by persons with different interests and education. An effort has been made to word all parts so that they can be understood by a high school graduate who reads them carefully and begins with the introductory chapters, perhaps using a dictionary from time

to time. Technical and scientific terms are explained where they are first used. If they are not remembered later, the glossary will help; words not found in the glossary may be explained on pages indicated by the index. Knowledge of high school chemistry and physics would be helpful but a little basic information on these subjects is included to assist readers unfamiliar with these subjects.

Some readers may wish to read the book in its entirety, some only the chapters or sections that interest them, and others may use it only as a reference book. Independent students are advised to skim it first, then to read carefully the parts that concern them for the time being, marking or noting sections that may need reviewing. Information desired while actually prospecting could be copied in a notebook, and the mineral-identification table is available separately. A person interested in learning only conventional prospecting is advised to study carefully Chapters 1 to 9 inclusive, then to read the first part of Chapter 14 and all of Chapter 17; he might wish to read other parts of the book later.

This book discusses briefly a variety of scientific and engineering subjects and some related classifications. These discussions may be understood better if a few general principles regarding science are explained at this point. In the broadest sense all natural science is one great system of knowledge and theories dealing with changes and movements of matter that are accompanied by transformations of energy. Limitations of our minds force us to divide natural science into branches and classifications, and we are inclined to forget that these are not fully distinct but are artificial and transitional, comprising the one large 'spectrum' of natural science.

Physics, the most fundamental branch of natural science, includes among other topics the study of the smallest particles of matter, which are grouped in the form of atoms. Chemistry deals with atoms and their groupings to form molecules, but the distinctions between the physical and chemical branches of science are not sharp. Astronomy deals with the general features, positions, and motions of bodies in space including the earth. Geology deals with the earth itself, much of this study being based on physical and chemical principles. Some divisions of geology are so transitional with physics and chemistry that they form specialties called geophysics and geochemistry, which have become so complex that many authorities refer to them as branches having the same rank as geology, and use the terms 'earth science' or 'geoscience' when referring collectively to all three branches. Some aspects of geology are so complex that they are divided into such specialties as mineralogy, the study of rocks themselves, and the study of ores and ore deposits, but these divisions are closely interwoven. Biology is the study of living organisms; paleontology is the study of fossils, which are the remains of living organisms preserved in rocks, and so forms an intimate transition between geology and biology. Geology and mining engineering also have many common aspects and transitions.

Scientists divide objects and processes into units and groups that are given distinct names for purposes of thought and discussion, but these are imperfect man-made distinctions. The species into which biologists divide plants and animals are useful and fairly distinct, but many subspecies, varieties, and hybrids are also recognized. Similarly, geology and prospecting could not be discussed without the names that are applied to minerals, rocks, ore deposits, and other related topics. In introductory courses students are generally shown straightforward, typical examples and specimens but in the field many transitions between typical examples are found.

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2 the foundations of geology

The different aspects of prospecting cannot be properly understood without some knowledge of the processes that form and change the earth's crust. An acquaintance with geology is essential for prospectors and is desirable for everyone, for it is a fascinating subject in itself and one that greatly enhances appreciation of our world. These processes are not difficult to understand, after a few fundamental facts have been grasped.

The study of the earth is based largely on two important principles whose truth has been demonstrated time and again. The first is that the earth is almost inconceivably old (3 to 4 billion years), and the second that it has undergone many, extensive changes since it was first formed and that these changes are continual. The earth's crust has long been and is being subjected to processes that result in the destruction of some parts and the construction of others. Its story is written in the rocks, and although it has not yet been completely interpreted, geologists have unravelled it to a fairly satisfactory degree and have proved beyond doubt that processes at work today could account for all the changes that occurred during the long ages of geological time. Therefore, although geology deals largely with events that took place millions of years ago, it is a very live subject because many of the processes that caused these events can be studied in operation at present.

THE DESTRUCTION OF THE EARTH'S CRUST

We usually think of such natural features as rocks, mountains, rivers, and shorelines as permanent. A little observation, however, will soon show that this is not so. Rocks are gradually disintegrated by frost and chemical action; mountains suffer landslides; rivers undercut their banks and change their courses; shorelines are eaten away by wave action. These are the more obvious changes taking place, but many others are constantly at work. These changes may seem insignificant in relation to the earth in general, but when it is considered that they have been going on for hundreds of millions of years, it will be realized that their cumulative effect is enormous. Such changes are the foundation of the science of geology.

The earth's crust consists mainly of solid rock, called bedrock, which is exposed at many places. Elsewhere it has a relatively thin covering of soil, sand, gravel, boulders, and angular fragments of rocks. This material is generally called *overburden* but, strictly, soils form a separate category. Both the exposed bedrock and the particles and fragments of rock in the overburden are constantly being attacked by agencies related in one way or another to the atmosphere.

The processes by which land surfaces are worn down are collectively called *erosion*. They include the more or less static agencies classed as *weathering*, the actions of moving water, winds, and glaciers, and the transportation of the products of erosion.

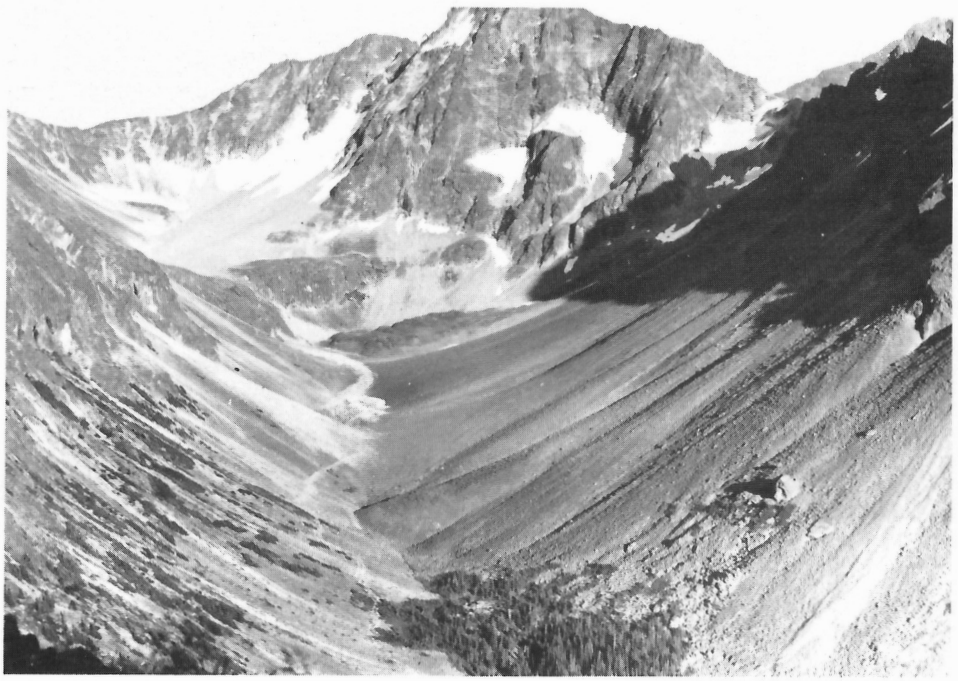


H. M. A. Rice 85280

Plate 5. Weathering along fractures in volcanic rock (basalt). Note tendency to weather in rounded masses.

The decomposition that takes place at the surface of a rock or along cracks in it is generally the result of exposure to moisture in the form of rain or melted snow and is appropriately called weathering. This effect can be seen on the exterior of old stone buildings, where the surface of the blocks is changed in colour and often has a rotten, crumbled appearance; the same changes occur in natural

exposures of bedrock or rock fragments. Only a few kinds of rock are soluble in pure water, but most kinds are soluble to some extent when water has accumulated certain substances such as carbon dioxide from the atmosphere and acids from the action of plants in the soil. Weathering is speeded by cracks in rock, which expose additional surfaces and also tend to concentrate solvent action. Another type of weathering is caused by alternate expansion and contraction of rocks during hot days and cool nights. By these means rocks flake off, commonly forming rounded surfaces. Still another type of weathering, common in mountains where low temperatures are frequent during summer nights,



E. D. Kindle 83033

Plate 6
Erosion in high mountains near Hazelton, B.C., also showing small alpine glaciers and cirques. Talus slopes are shown along the sides of the valley.



Plate 7
Erosion in mountainous terrain, St. Elias Mountains, B.C. (RCAF T7-22L).

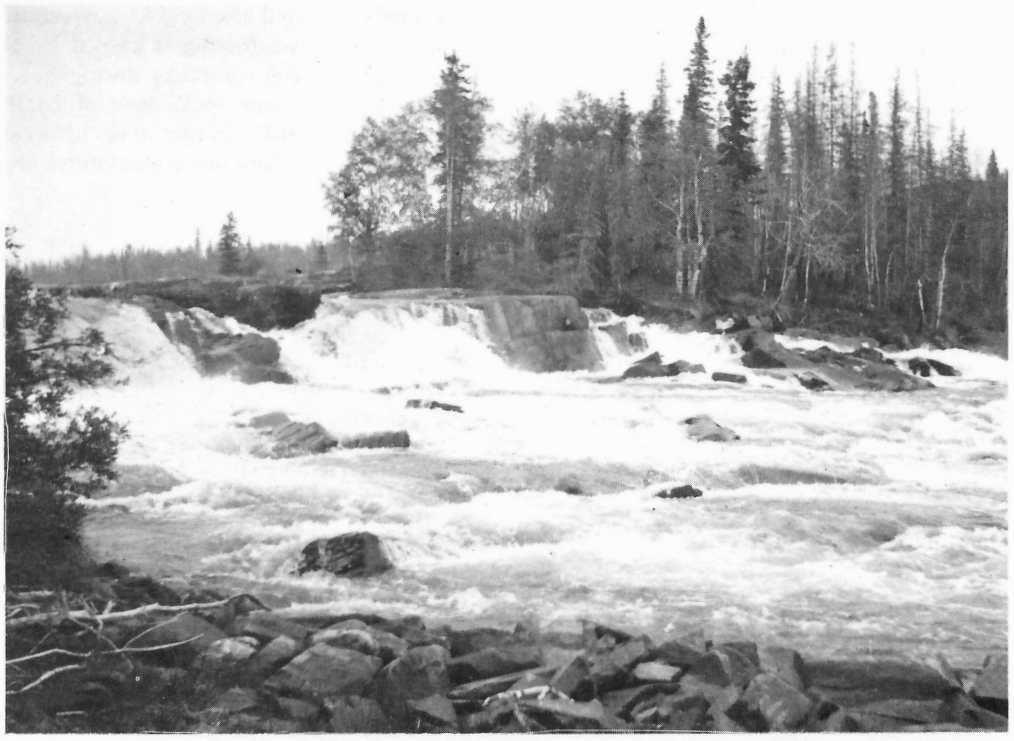


Plate 8
Erosion in Precambrian rocks at falls and rapids on Yellowknife River.

A. W. Jolliffe 84382

results from the expansive force of freezing water that fills cracks. This causes pieces of rock to split away from the main mass, and is largely responsible for the piles of angular fragments that accumulate at the base of a cliff and are called 'scree slopes' by mountaineers and 'talus slopes' by geologists. Masses of overburden or rock moved downward by gravity form landslides.

One of the most powerful agents of erosion is water in motion. Everyone is familiar with the gullies that form in fields after heavy rains have washed away some of the soil, and with the way that banks are undercut and caused to slump by streams and waves. Less obvious is the way powerful streams of water in rapids and falls scour the bed of a creek or river and detach blocks of solid rock. Streams in flood move blocks and boulders, rolling them along and bouncing them against one another so that they gradually are worn and cracked into smaller and smaller pebbles and grains. Besides the action of the water itself, the innumerable sharp particles of sand carried by a swift stream have an abrasive effect that slowly wears down the hardest bedrock or boulders in the path of the current. Similarly, waves pounding the shores of lakes and seas wear the shores back and cause the detached material to become smaller, both by the direct action of the water and by the abrasive effect of swiftly moving sand particles. Streams gradually widen their valleys by changing their courses from time to time, and slowly deepen the valleys. These changes can at some places be noticed within the lifetime of a man, and when it is realized that the erosive processes may continue for millions of years it is not hard to understand why running water is so effective in wearing down the land and in sculpturing cliffs, hills, and valleys.

Although not so universally effective as running water, winds are important causes of erosion in many regions. The effect of dust storms in blowing away valuable top soil is a serious problem in many agricultural districts. Sandstorms not only cause sand to be moved from place to place, but the abrasive effect of sand particles blown swiftly against larger rock fragments and exposures of bedrock acts like a sand-blast in wearing and polishing them.



L. J. Weeks 88162

Plate 9. Erosion along sea-coast, Gulf of St. Lawrence. The rock is sandstone.

Plate 10A
Ice-fields and valley glaciers. Coast Mountains, B.C. (RCAF A2829-25).



Plate 10B
A large landslide in British Columbia.

S. Walter

Discussion of glaciers, which are powerful agents of erosion, has been left until the last because they are less familiar and so require more explanation. Perched near the summits of high mountains such as those of western Canada are many masses of ice, called alpine glaciers, that survive even the hottest summers. Larger glaciers, called icefields, exist in a few mountainous places and cover great areas in such arctic regions as Baffin Island and Greenland. Glaciers

are formed wherever more snow falls in winter than melts in summer. In such places, the weight of fresh snow causes the underlying snow to be compacted and finally to recrystallize as solid ice. The lower part of a glacier moves slowly by plastic flowage because of the weight of ice and snow above it. Thus the frozen water that falls as snow gradually moves to the lower end of a glacier where it melts to feed a stream. If the rate of melting is less than the rate of accumulation of fresh snow, a glacier increases in size and is said to be advancing; if the melting exceeds the accumulation the glacier grows smaller and is said to be retreating. Most glaciers are retreating at present because we are living in a relatively mild period, but at several times in the past the climate was cold enough to cause great sheets of ice, up to thousands of feet thick, to cover large parts of continents. After the icesheets had melted, but before the climate had moderated to present conditions, alpine glaciers were much more numerous than they are today and they joined to form long tongues of ice called valley glaciers which flowed slowly down the larger valleys of mountainous regions.

Glaciers erode in several ways. The ice in the base flows around fragments of rock and carries them along to be deposited when and where melting occurs. In addition, these fragments act like bits set in a gigantic slowly moving tool, the larger ones gouging the overburden or bedrock in the path of the glacier and the smaller ones striating and polishing knobs of bedrock into the familiar grooved and rounded outcroppings so common in many parts of Canada. Also, rock fragments fall from the sides of mountain peaks and valleys onto alpine and valley glaciers and are carried along on the surface of the ice until melting takes place. At the heads of alpine glaciers the ice freezes in cracks in rocks and around rock fragments, and plucks them away to form semicircular basins called cirques.

Thus the land areas that exist today are slowly being worn down by natural processes, and the products of erosion are transported and deposited in ways explained below. These processes of wearing away and depositing elsewhere have operated in cycles again and again during the long ages whose history is recorded in the strata laid down during successive geological periods. Except for a slow increase in the amount of salts carried in solution in the waters of the oceans, the removal of material from the land areas has always been balanced by the deposition of sediments.

TRANSPORTATION AND DEPOSITION

Eroded material is moved slowly towards the sea, sometimes being trapped permanently at an intermediate point. The movement takes place in several ways. A slow downward creep of rock fragments and soil occurs along the sides of mountains and hills and on slopes below cliffs. This movement is often hastened by slides caused by excessive soaking of the material by water, or by the expansive action



Plate 11
View of White and Yukon Rivers, Yukon Territory, showing streams carrying sediments and depositing them along the valley floors (RCAF T1-36R).



Plate 12
An alluvial fan forming a delta.

W. S. MacKenzie 120527

of frost, or by snow avalanches. When material transported by creep or slides reaches a stream it is added to the normal load of sediment that the stream itself has eroded. Some of the coarser material carried by streams is deposited as bars of boulders, gravel, or sand; the finer material is carried farther, to be deposited as sand, silt, or clay in lakes or in the sea. The debris formed by wave erosion is sorted by currents, so that the larger fragments and pebbles remain as beaches, whereas sand is deposited in shallow water and mud in deeper water. Much of the material that is carried in solution to the sea remains in this state to make the complex brine of sea-water, which, contrary to popular belief, is not composed of water and common salt only, but is a mixture containing at least minute amounts of almost every element. Some of these elements, however, are deposited from sea-water by chemical reactions, or by evaporation in tidal ponds, and thereby form deposits of lime, salts, and various other chemical sediments. As already mentioned, wind is also an agent of erosion, and it transports and deposits large amounts of dust and sand in certain regions. Because both water and wind drop sediments intermittently and because there are slight changes in the colour and size of the particles so deposited, many sediments formed by these agencies are clearly stratified, the thickness of individual beds varying from thin layers to strata many feet thick. Glaciers carry clay, sand, and larger angular or rounded fragments of rock and deposit these materials as *till* in irregular sheets and ridges called *moraines*; or the finer material may be washed into temporary lakes and rivers formed by water from the melting ice, and deposited as stratified glacial clay, silt, sand, or gravel.

Sediments formed in any of these ways may later be eroded while still in an 'unconsolidated' state such as ordinary sand and gravel and be re-deposited elsewhere, or they may remain and be buried deeper and deeper by overlying sediments until they become compacted and cemented into hard sedimentary rocks of the various kinds described later. Certain parts of the earth's crust contain much thicker accumulations of sedimentary and volcanic rocks than other parts. These were developed in large, shallow, trough-like basins called *geosynclines*, which lay offshore from land being eroded and which gradually sank as more and more strata were laid down. Sediments deposited in seas are called *marine*, and sediments deposited in fresh water or directly on land are called *continental*.

VOLCANOES AND PLUTONS

So far only the strata produced from the wearing away of pre-existing rocks have been discussed. Associated with such strata in many parts of the earth's crust are rocks of other kinds, consolidated from molten lava that once spread over the land or under seas or lakes, or from molten or other material that did not reach the surface. These rocks are grouped under the general name *igneous* (from the Latin word for fire) and are divided into two main classes: *volcanic* rocks formed at the surface, and *plutonic* rocks formed below the surface. Volcanoes and the lavas they emit are among the most spectacular natural phenomena, and as they can be studied in several parts of the world today, the origin of the various kinds of volcanic rocks is well understood. Plutonic rocks cannot be seen in process of formation because they are emplaced below the

surface and are exposed long afterwards by erosion. Therefore, our knowledge of the interior and of the origin of plutonic rocks is based on indirect evidence outlined below.

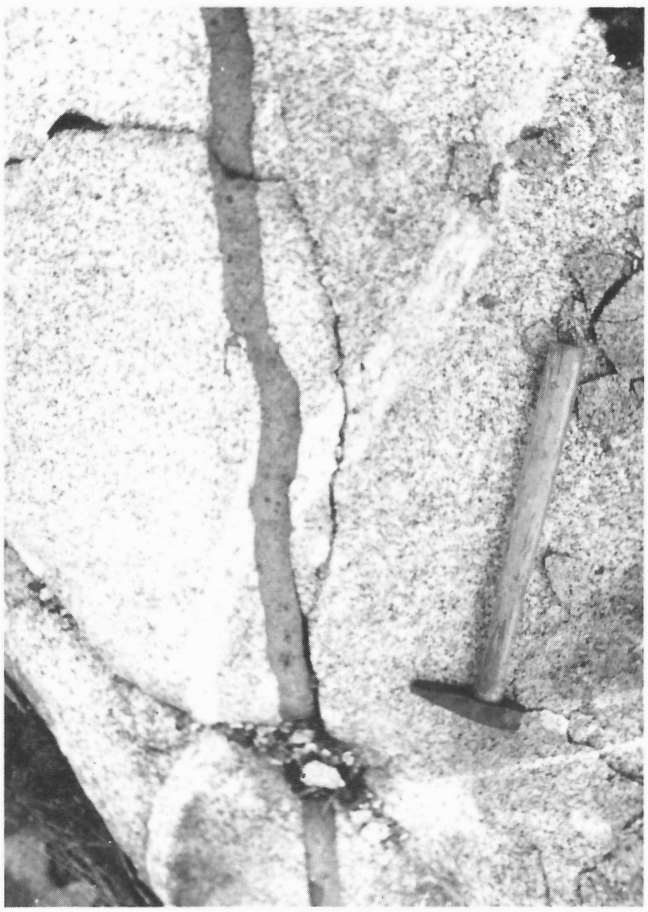
The temperature within the earth's crust increases downward at an average rate of about 1°F for each 60 feet in deep mines and wells; this rate of increase is probably not maintained at great depths but the interior certainly has a high temperature, because hot waters of certain springs and hot lava come to the surface in many places. The heat is probably in large part generated by the natural disintegration of radioactive elements such as uranium. It is known, however, that the pressure also increases downward, and although the temperatures at depth are great enough to melt the rocks if they were at the surface, the pressures are so high that much of the material is forced to remain in a solid or plastic state. This evidence is substantiated by the behaviour of earthquake waves, which travel as if the interior was mainly solid; they also provide strong evidence that the interior is divided into zones of different compositions, which probably grade into one another. Another line of evidence shows that the total weight of the earth can be calculated from the effects of gravitation. The weight is much more than it would be if the interior consisted of the same relatively light rocks that predominate in the parts of the crust that can be examined. Therefore, it is clear that the interior must consist of heavy, dense material whose weight at different depths can be predicted mathematically. A third type of evidence is provided by meteorites, which occasionally reach the earth. They are apparently fragments of disintegrated planets or other, smaller bodies in space, so they provide evidence regarding the probable interior of the earth. Some meteorites are heavy, dark rock and others are a still heavier mixture of nickel and iron; therefore it is reasonable to suppose that the interior of the earth is composed of similar material.

From the lines of evidence mentioned above, which



Plate 13
A stock and small masses, dykes, and sills of granite and related rocks (white) intruding metamorphosed sedimentary rocks (dark grey), in the Canadian Shield, Northwest Territories. Three long, young diabase dykes (dark grey) can also be seen. The black areas are lakes. The air photograph covers about three square miles (RCAF A5619-36).

corroborate one another, a fairly reliable concept of the interior of the earth has been established. Study of earthquake waves indicates that crustal rocks approximately like those we can study at the surface are about 15 to 40 miles thick in continental areas and about 5 miles beneath the oceans. Beneath the crust is less elastic material forming the *mantle*. This is probably close to the melting point in most places and molten when and where temperature is raised or pressure is lowered. The material behaves like a solid during short periods of stress but like plastic flowage



H. M. A. Rice 85468

Plate 14. Granite intruded by a small dyke of aplite, which in turn is cut by a dyke of lamprophyre. The rock names are explained in Chapter 3.

during longer periods; pressure from such flowage may be a cause of movements in the crust. The thickness of mantle has been estimated to be about 1,800 miles. It transmits waves like a solid and probably has about the same compositions as ultramafic rocks and iron–silicate minerals (*see* Chapter 3). The material between the mantle and the earth's centre has a radius of about 2,200 miles, is thought to consist of nickel and iron, and appears to be divided into two zones: an inner solid core and an outer liquid zone.

In deeply eroded mountainous regions, or regions that were once mountainous, it is common to find bodies of coarse-grained crystalline rocks such as granite and diorite known as *plutonic* rocks or *plutons* to distinguish them from other kinds of igneous rocks. The smaller bodies of plutonic rocks are called *stocks* (*see* Fig. 1), and the larger ones, if their areas are more than 40 square miles, *batholiths*. The

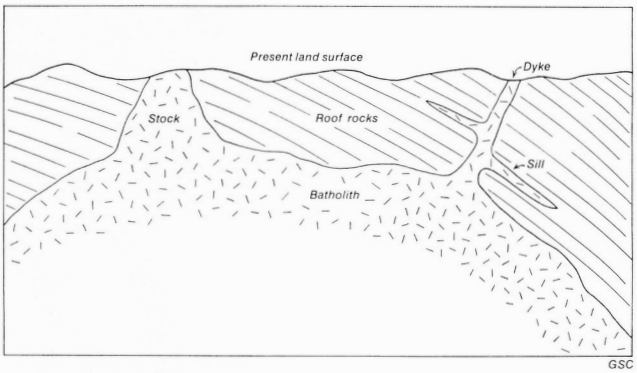


Figure 1. Diagrammatic illustration of a batholith not yet exposed by erosion, with related stock, dyke, and sills.

rock must have crystallized slowly at thousands of feet below the surface to permit growth of the fairly large crystalline grains that characterize plutonic rocks. All this material was formerly believed to have originated in the mantle below the crust, in large liquid or plastic masses called *magmas*, and variations in composition between different kinds of plutonic rocks were generally believed to have resulted partly from a splitting of material within the magma, and partly from reaction of the magma with the adjoining crustal rocks. There are, however, certain granitic rocks that show evidence of having crystallized entirely from reworked crustal rocks, particularly sedimentary ones, probably at considerable depths below the existing surface, and after the crustal rocks had been impregnated with solutions coming from greater depths. Some geologists now believe that all plutonic rocks originate by this process, known as *granitization*, but most consider that some rocks are formed by granitization and some by crystallization from conventional liquid magma.

There are also finer grained igneous rocks with the same ranges of composition as plutonic rocks. They have three characteristic forms: small irregularly shaped masses whose form has not been given a specific name; long, narrow bodies called *dykes* that fill fractures crossing other rocks; and thin bodies called *sills* that were injected parallel with the beds of sedimentary rocks, the flows of volcanic rocks, or the bands of metamorphic rocks described later. The rocks of dykes and sills owe their finer state of crystallization partly to their smaller sizes, which permitted more rapid cooling, and probably also some of the molten material penetrated closer to the surface that existed at the time of their emplacement and thus could cool more quickly. Dykes, sills, stocks, and batholiths are commonly termed intrusions, but, particularly for stocks and batholiths, it is now considered better to call them *plutons* because some were probably formed by such processes as granitization without being moved into position as true intrusions are.



Plate 15
A sill of granite intruding sedimentary rocks.

J. G. Gray 85400



Plate 16
Diabasic gabbro sill of late Precambrian age changes horizons along a fracture, Arctic Islands.

R. L. Christie 131185

Lavas, which have about the same compositions as the rocks of dykes and sills, issue from volcanoes and fissures. They flow on the surface or under water, and cool and crystallize fairly quickly because they come in contact with air, cool surface soils and rocks, or water. The various kinds of lavas correspond to the kinds of plutonic rocks, the only essential difference being in the size of the component crystals. Volcanic rocks of another class are formed from the accumulations of volcanic ash and larger fragments that are ejected from many volcanoes. Lavas, ash, and volcanic fragmental rocks are commonly clearly interlayered because of intermittent deposition.

MOVEMENTS IN THE EARTH'S CRUST

The crust of the earth is constantly subjected to stresses that cause deformation in the form of cracks (along which movement of one block of the crust relative to another may take place), great downwarpings and upwarpings, and contortions on smaller scales. These movements are no doubt caused, to a large degree, by the slow increase in the weight of sediments accumulated in large basins of deposition, the load forcing these basins to sink deeper and probably causing a yielding of the plastic material beneath the crust. There is doubtless also a corresponding lessening of pressure at depth in highland areas as these are slowly reduced in weight by the effects of erosion. Thus the relatively flat surfaces worn down by erosion are slowly uplifted to form plateaux. The uplift causes streams to flow swifter and this increases their erosive power, causing them to dissect a plateau into a second generation of mountains and valleys. Such warpings, however, do not explain the cause of the great lateral stresses required to produce some of the phenomena described below; theories have been developed to explain them but the origin of the forces is not yet fully understood.

The various forms of movement that take place in the rocks of the crust and the *structures* that result are of the utmost importance to prospectors because many mineral deposits are related to them. The main kinds of geological structures are *fractures*, *faults*, and *folds*.

Fracturing and Faulting

Rocks yield to stress by fracturing, by movement of solid masses, by recrystallization that produces chemical compounds that are stable under the increased pressure, and by plastic flowage under great pressure. The simplest structures produced by stresses in rocks are fractures (joints), which range from small cracks to fractures 100 feet or more long.

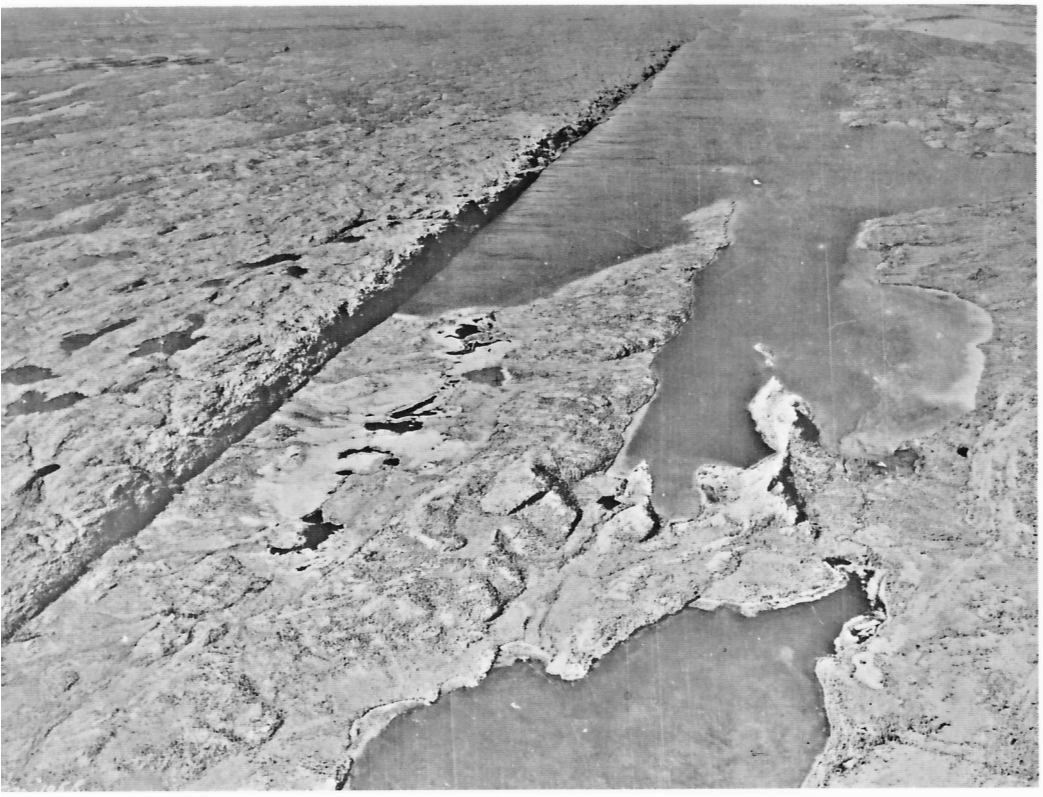


Plate 17
Erosion along a prominent fault in the Canadian Shield, Northwest Territories (RCAF A5120-105R).

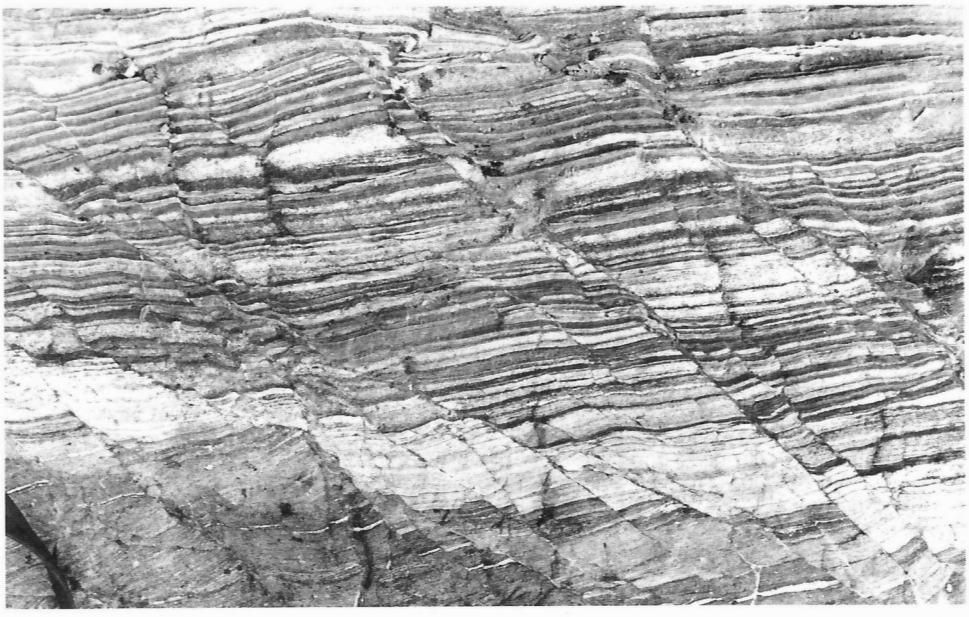


Plate 18
A series of small normal faults in thinly bedded Precambrian quartzite (iron-formation) (*see* Chapter 3). The darker beds are quartzite containing considerable quantities of the mineral magnetite.

J. D. Bateman 88218

They commonly occur in groups in which several fractures are parallel with one another or intersect one another at angles that are more or less uniform for a particular group. Continued stress may cause the rock at one side of a fracture to move relative to the other, producing what is called a *fault*. The walls of faults are usually polished and grooved, forming characteristic surfaces called *slickensides*. The movement along a fault commonly grinds the rock to form a clay-like deposit of crushed rock called *gouge*, which may range from a fraction of an inch to several feet in thickness. Instead of producing gouge, the movement along a fault may cause the formation of a *shear zone*, where the displaced rocks are separated by a band of sliced or sheared rock; or the rock may be crushed into angular fragments, thus forming what is called a *crushed zone* or *brecciated zone* between the walls of the fault. Large faults can be traced for several miles; the largest extend for hundreds of miles. The displacement of the rocks at one side or other

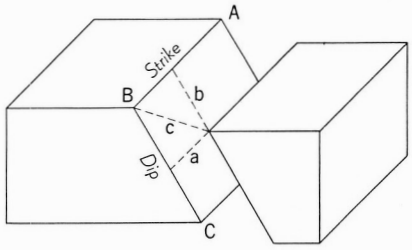
of such faults is very great, being measurable in hundreds of feet, or even in miles. The movement along large faults causes intense vibration in the form of an earthquake.

In order to understand the descriptions of faults contained in geological and mining reports it is necessary to be familiar with a few more definitions. Although a fault is represented by a line on a geological map or plan, the movement takes place along a surface that is called the *fault plane* (*see* Fig. 2A). The bearing of this plane, expressed as a compass direction, is the *strike* of the fault plane. Its downward slope is the *dip* or *inclination*. Some fault planes are vertical, but most are inclined at an angle and, if so, the block of rock lying above the fault plane is called the *hanging-wall* and the block below is the *footwall* (*see* Figs. 2B and 2C). If the hanging-wall appears to have moved downward with respect to the footwall, the fault is a *normal fault*, whereas, if the hanging-wall appears to have been pushed upwards, the fault is a *reverse fault* or *thrust fault*. As a rule, the direction of movement is such that it can be measured horizontally as well as vertically. The horizontal displacement is then called the *strike slip* and the vertical displacement is the *dip slip*, whereas the actual movement is termed the *net slip*, as explained on Figure 2A. A fault whose movement is almost entirely in a vertical direction is sometimes called a *dip slip* fault or simply a *dip fault*, and one that is mainly in a horizontal direction is a *strike slip* or *strike fault*. Horizontal displacement of a fault is sometimes referred to as *right-handed* or *left-handed*, depending on the direction of the apparent movement. For example, as illustrated on Figure 2D, if the observer stands at the contact of a bed, vein, or dyke that has been faulted, facing the fault, and if the corresponding contact at the other side of the fault is to his right, the fault is a right-handed one. The word *contact* is a common one in geological descriptions, referring to the line or surface between two unlike bodies of rock.



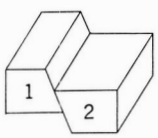
H. H. Beach 86549

Plate 19. A fault plane exposed by erosion.



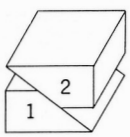
Elements of faults and fault movement

Plane ABC *represents a fault plane*
Line AB *represents the strike of the fault*
Line BC *represents the dip of the fault*
Line a *indicates the strike slip*
Line b *indicates the dip slip*
Line c *indicates the net slip*



Blocks illustrating a normal fault

1, *footwall*; 2, *hanging wall*



Blocks illustrating a reverse or thrust fault

1, *footwall*; 2, *hanging wall*

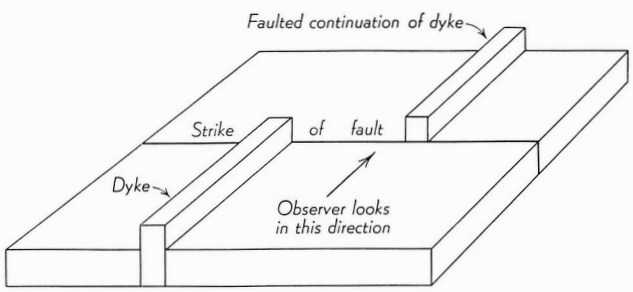


Illustration of right-handed fault movement

A perspective drawing showing a dyke projecting above the general land surface because of its resistance to erosion, and displaced by a right-handed fault

Figure 2. Diagrammatic illustrations of faults.

Folding

Rocks also yield in the solid state by buckling into folds, which range in size from tiny puckerings to sweeping arches and troughs miles wide. A fold that is arched is an *anticline*, and its trough-like neighbour is a *syncline* (*see* Fig. 4). An imaginary line along the crest of an anticline or along the lowest part of a syncline is the *axis* of the fold, and the sides of the fold are the *limbs*. Beds of stratified rocks are commonly found in tilted positions, either because they are on the limb of a fold or because uplift has taken place in an unequal manner. Geologists speak of the position of strata as the *attitude*, and they measure and record the attitude of inclined beds by *strike* and *dip*. The strike is the bearing of an imaginary line drawn horizontally along the plane of inclination, and the dip is the angle between the horizontal and the plane of inclination; these terms are illustrated on Figure 3. Similar measurements define the attitudes of fractures, dykes, and veins.

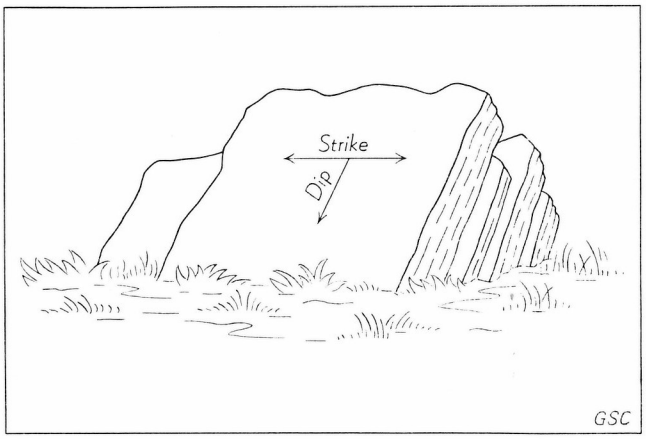


Figure 3. Diagram showing an outcrop of beds of sedimentary rocks to illustrate directions in which dip and strike are measured.

Mountain Building

Fracturing, faulting, and folding are commonly associated in a complex process called *mountain building* (orogeny), by which large quantities of stratified rocks that accumulated in great sedimentary basins are uplifted and cast into the complicated folds and fault blocks characteristic of mountain chains, and by which older mountainous areas worn down by erosion are uplifted and rejuvenated into secondary mountains. These processes are usually accompanied by igneous activity; in fact, the generally held concept of the origin of magmas is that the local release of pressure caused by upwarping permits the liquefaction of deep-seated rocks that are normally prevented by pressure from existing in a molten state. Large-scale structural disturbances such as are caused by orogenies are called *tectonic* disturbances and comprise the subject *tectonics*.



E. W. Mountjoy 117523

Plate 20
A thrust-fault in the Rocky Mountains. Steeply dipping sedimentary strata at left are thrust over other sedimentary rocks lying in a syncline that is overturned to the right.



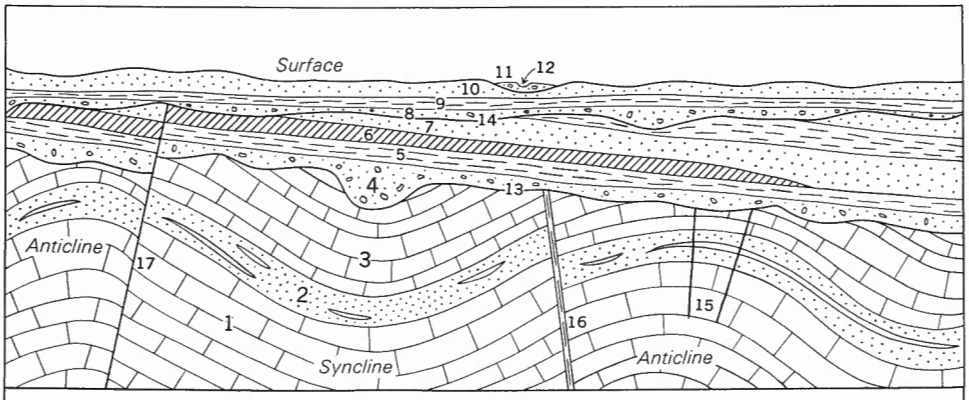
R. A. Price 6-7-65

Plate 21
Folds in interbedded limestone and shale, Rocky Mountains.

GEOLOGICAL SUCCESSION

The various sedimentary and igneous rocks that underlie a particular region, described in the order of their ages of deposition or intrusion, constitute what is called the geological succession (*see* Fig. 4). This varies from place to place because deposition occurred at one locality while erosion went on at another, because intrusions and volcanic activity occur only at certain times and places, and because many of the rocks once formed may subsequently be destroyed by erosion. Geological conditions differ from place to place in another respect, namely, by the manner in which the rocks are tilted, folded, or faulted.

served as fossils. Life must have begun early, however, because rocks formed about 570 million years ago contain fossilized remains of many different, fairly advanced organisms, which undoubtedly were not the first forms of animal life. Many beds of sedimentary rocks less than 570 million years old contain fossils, and in a few places fossils of primitive forms of life have been found in older beds. It has been proved repeatedly that the fossils deposited during any one period were much the same in any part of any continent, whereas the fossils of each period show distinct differences caused by the decline of certain species and the advancement of others. These facts are of the greatest assistance to geologists, who are thus able to use fossils to correlate rocks



An ancient series (1-3) *consists of three conformable formations comprising limestone* (1), *sandstone with lenses of shale* (2), *and younger limestone* (3). *These beds were folded into anticlines and synclines, after which the upper ones were eroded to form the ancient land surface* (13). *This surface was submerged and on it was deposited another conformable series* (4-7), *comprising conglomerate and sandstone* (4), *shale* (5), *lava flows* (6), *and sandstone* (7). *These formations and those of the underlying, folded series were uplifted and tilted. Erosion then produced another land surface* (14). *This was submerged and a third series* (8-10) *was deposited, comprising conglomerate and sandstone* (8), *shale* (9), *and sandstone* (10). *The beds of this series remain in their original horizontal position. A modern stream* (12) *has cut a valley in formation* (10) *and has deposited sand and gravel* (11). *The lines* (15) *represent fractures older than surface* (13). *A fault,* (16), *which has formed a wide shear zone, is also older than surface* (13). *A later fault,* (17) *is younger than surface* (13) *but older than surface* (14).

GSC

Figure 4
Cross-sectional diagram illustrating geological successions.

Despite these complications, by comparing the successions in many different areas, geologists have established a timetable whose broad features are applicable to all the continents. This has been possible largely because of the presence of fossils in most sedimentary rocks laid down during the latter part of geological time, dating from the beginning of the Cambrian period, as explained below. Fossils are imprints or remains of plants or animals buried in sediments and preserved after the sediments became rocks. The time of the beginning of life on our planet is unknown because the simplest living organisms, which no doubt appeared first, lack shells or skeletons that could be preserved as fossils. Life must have begun early, however, because rocks formed about 570 million years ago contain fossilized remains of many different, fairly advanced organisms, which undoubtedly were not the first forms of animal life. Many beds of sedimentary rocks less than 570 million years old contain fossils, and in a few places fossils of primitive forms of life have been found in older beds. It has been proved repeatedly that the fossils deposited during any one period were much the same in any part of any continent, whereas the fossils of each period show distinct differences caused by the decline of certain species and the advancement of others. These facts are of the greatest assistance to geologists, who are thus able to use fossils to correlate rocks of the same age in different regions, and to work out the true succession in regions where certain beds are missing or where beds are overturned by intense folding.

Study of the successions in different parts of the world has shown that, for the earth as a whole, geological time can be divided into definite intervals of great duration. When these age intervals were agreed upon, those occurring between stages of greatest mountain-building activity were called *eras* and *eons*, and divisions within eras, separated by much less intense crustal disturbances, were called *periods*. Because of these cycles of mountain-building, uplift, and subsequent erosion and deposition, the rocks

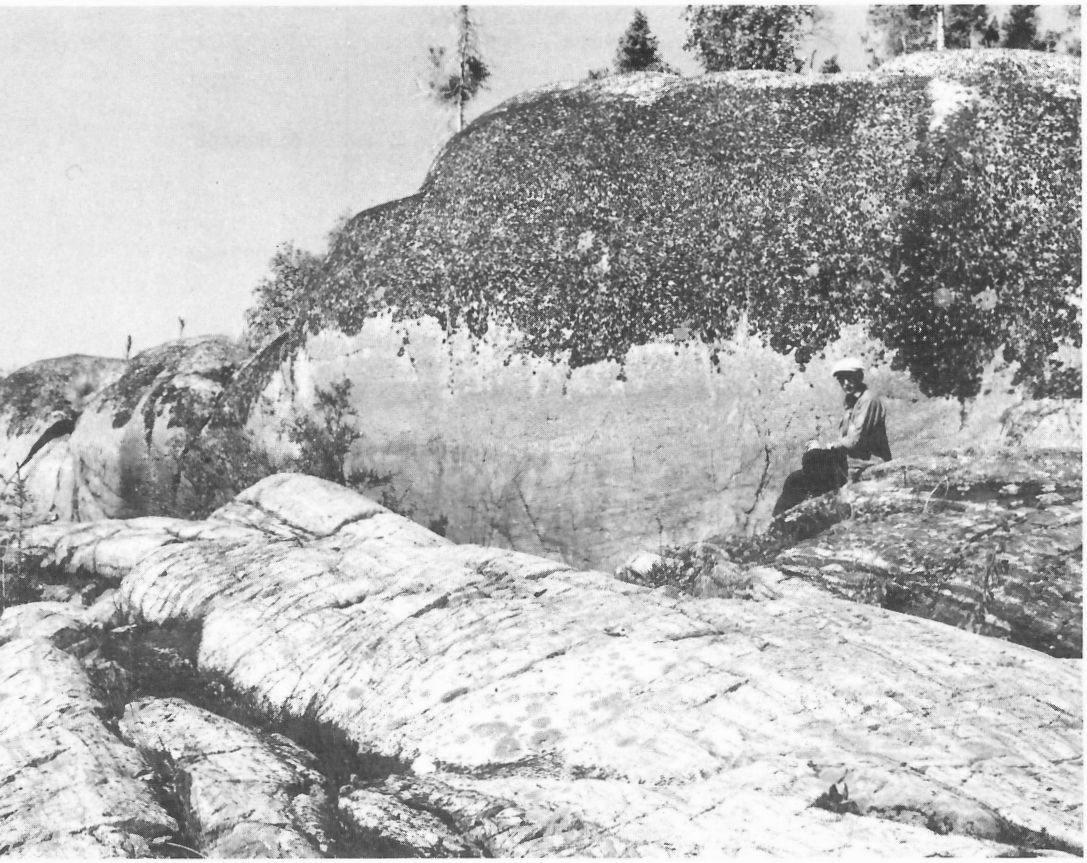
representing different eras or periods are commonly separated by ancient erosion surfaces called *unconformities* (*see* Pls. 22 and 23). These are of two kinds: *parallel unconformities* where the strata above and below are horizontal or equally inclined, indicating that erosion and perhaps uplift took place but that no folding occurred, and *angular unconformities* where the strata below are folded or inclined in quite a different way to those above the unconformity, thus indicating that the older rocks were folded or tilted before the younger ones were deposited.

Because rocks formed during the younger periods and eras are better preserved it is easier to make distinctions between them; therefore, the time units that have been agreed upon are progressively shorter, as illustrated in the accompanying table, which, like all geological tables and legends, has the younger units at the top.



J. W. Griffith 134621

Plate 22
Unconformity between basal Proterozoic (Huronian) conglomerate and Archean basement rock.



C. K. Bell 117824

Plate 23
Unconformity between flat-lying younger Precambrian conglomerate and arkose, and steeply dipping older Precambrian quartzite. The black material in the upper part of the photo is lichen.

Although prior to 1920 geologists did not have the means now available of estimating the ages of rocks, they knew that geological time extended for many million years. This conclusion was based on measurements of the average rate of accumulation of sediments being deposited in modern times. When this rate was applied to the enormous thicknesses of sedimentary rocks that were measured for one period after another it was obvious that each period lasted several million years. This was corroborated in another way when it became clear that the forms of life in one period had evolved from those of the preceding period, and that such changes could only have been accomplished very slowly. Today astronomers are convinced that the earth was formed at least 3 or 4 billion years ago, and this is borne out by the application of methods now available for dating certain minerals, rocks, or times of principal mountain building. The basis of these methods is that certain elements disintegrate slowly into other forms (isotopes) at known rates. Through delicate analyses, particularly of the ratios of isotopes of the elements potassium and argon, ages have been estimated fairly closely. The way the results of the large number of such determinations now available combine to give a concept of the main events of geological time inspires confidence in their approximate time ranges.

The dates* for the main subdivisions are shown in the accompanying table. Additional data will probably cause some changes in this information, but the crude orders of magnitude are considered reliable.

The oldest time, called the Precambrian, lasted more than five-sixths of the entire span of geological time. Because of the scarcity of fossils in Precambrian rocks and because these rocks are much deformed and, therefore, difficult to trace from one region to another, it has not been possible to subdivide the Precambrian as finely as the succeeding times. In Canada, Precambrian time is divided into two eons: Early Precambrian or Archean, and Late Precambrian or Proterozoic. Stockwell has recently divided

* Geological Society Phanerozoic time scale; *Quart. J. Geol. Soc. London*, vol. 1205, pp. 260–262, 1964.

Stockwell, C. H.: Fourth report on structural provinces, orogenies, and time-classification of rocks of the Canadian Precambrian Shield; *in* Age determinations and geological studies; *Geol. Surv. Can.*, Paper 64-17 (Part II), 1964.

Geological Time Scale

Eon	Era		Period	Characteristic life	Total estimated time in years
	Cenozoic		Recent Pleistocene	Man	1,500,000
		Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Mammals and modern plants	65,000,000
	Mesozoic		Cretaceous Jurassic Triassic	Reptiles	225,000,000
	Paleozoic		Permian Carboniferous	Amphibians	
			Devonian Silurian	Fishes	
			Ordovician Cambrian	Higher invertebrates	570,000,000
Late Precambrian (Proterozoic)	Hadrynian			Primitive invertebrates and algae	880,000,000
	Helikian				1,640,000,000
	Aphebian				2,390,000,000
Early Precambrian (Archean)					3,000,000,000 or more

the Late Precambrian into three eras: Aphebian, Helikian, and Hadrynian. It has not yet been possible to divide these into periods, nor to divide the Early Precambrian into eras, although names have been applied in some localities.

Precambrian time ended, in most regions, with a pronounced interval of erosion which was followed by the Paleozoic era, and in turn by the Mesozoic. The youngest Precambrian strata in some regions, however, grade upward into those of the oldest Paleozoic. The youngest era is the Cenozoic, which is divided into several relatively short periods. The oldest of these form collectively the 'Tertiary', the third large time division after the Late Precambrian. The Tertiary was followed by the Pleistocene period, when the climate of the northern hemisphere became colder than normal, causing great glaciers and ice sheets to form over much of North America, Asia, and Europe. The climate then became warmer, causing melting of the ice, and these conditions of cold and warmth alternated so that four glacial stages occurred during Pleistocene time.

In the preceding paragraphs, only time terms were explained. Geologists also have a standardized way of distinguishing units of sedimentary and volcanic rocks. The smallest sedimentary unit is called a *bed* or *stratum*, which may be a fraction of an inch or many feet thick. Individual units of lava are called *flows*. The smallest unit that can practicably be shown on a geological map is called a *formation*. In rare instances a formation may consist of a single bed or flow, but most formations consist of a succession of beds or flows, or both, deposited during a short interval of geological time. They may be composed of only one kind of rock, or alternating beds of different kinds. Formations are customarily given names, such as 'Ottawa Formation' or 'Belly River Formation'. Some formations have been traced for hundreds of miles, but all end eventually, either by lensing out or by grading into other formations. Prospectors are prone to use the term in other ways, speaking of 'granite formation', 'lime formation', 'favourable formation', etc., but such usages should be avoided except for 'iron-formation', which is a recognized expression. Two or more formations in succession, related in such a way that it is desirable to refer to them collectively, are a *group* and are given names such as the 'Windsor Group'. A complete succession of formations for any one period can rarely be found, but where discovered is called a *system*, such as the 'Cambrian System'.

The ages of intrusive rocks can be estimated from the ages of the rocks they intrude. For example, if a body of granite intrudes the youngest Triassic strata and is overlain unconformably by earliest Cretaceous ones, it must have been intruded and unroofed by erosion during the Jurassic period; and as the erosion would require much time, the intrusion probably took place early in Jurassic time.

Suggestions for Additional Reading

This chapter provides only a brief outline of the main principles of geology, and is included so that geological matters discussed in the remainder of the book may be understood by the general reader and the beginner in prospecting. Prospectors will benefit from further knowledge of the subject; they will find it a most interesting study, and can pursue it by attending lectures or taking a correspondence course (*see* Chap. 6) or by reading some of the books available. Any of the recent textbooks used in introductory courses at universities would be suitable but fairly expensive. Some less costly books are listed below, followed by references to a few more expensive ones.

Carson, Rachel L.
1951: The sea around us; Mentor Books; New American Library.
This book contains very clear and interesting accounts of the parts the oceans play in erosion and in the formation of sedimentary rocks, as well as other subjects of interest to the student of geology.

Fearnsides, W. G., and Bulman, O.M.B.
1945: Geology in the service of man; Pelican Book A123; published by Penguin Books.
An inexpensive book on elementary geology, including sections on geological maps and mineral deposits. Although the treatment and examples are based largely on the geology of Britain, this book would be useful as additional reading for a beginner.

Himus, G.W.H.
1954: A dictionary of geology; Penguin Reference Books.
This inexpensive book provides definitions of numerous geological terms, names of rocks, etc.

MacLean, A.
1947: Geology for the layman; Northern Miner Press, Toronto, 2nd ed.
A good, short, introductory handbook on geology.

Raistrick, A.
Teach yourself geology; Hodder and Stoughton, Toronto.
This introductory book is No. 57 in the "Teach Yourself" series.

Read, H.H., and Watson, J.
1966: Beginning geology; St. Martin's Press.
A general 'orientation' book on geology with particular emphasis on the British Isles.

Walker, J.F.
1953: Elementary geology applied to prospecting; B.C. Dept. Mines, Victoria, B.C., rev. ed.
A useful elementary book on geology, mineralogy, and prospecting, with particular reference to British Columbia.

Eardley, A.J.
1965: General college geology; Harper & Row, New York, Evanston, and London.
An excellent but expensive introductory textbook including many Canadian illustrations.

Mather, K.F.
1964: The earth beneath us; Random House, New York.
An excellent, but expensive, general book on geology written for "the intelligent layman."

Shelton, J.S.
1966: Geology illustrated; Freeman, San Francisco and London.
A book for laymen, containing short discussions of geological processes and phenomena, and numerous good illustrations, mainly of places in United States.

3 minerals and rocks

MINERALS

Minerals are the material of which the rocks and ore deposits of the crust of the earth are composed. A prospector should be able to recognize the main rock-forming minerals and the principal commercial minerals, as well as some of the less valuable ones that are commonly associated with valuable minerals and that may, therefore, be clues in prospecting. From time to time he may need to learn to recognize a few additional minerals for which there is a special demand. He should also be acquainted with the general appearance of ores so that he will be able to recognize occurrences of possible value even if he cannot identify the mineral or minerals concerned. Mineralogy is a large and complicated subject; a competent prospector does not need to have an extensive knowledge of it but he should be well grounded in the fundamentals. The following sections explain the general principles of mineralogy and discuss the additional knowledge that should be acquired and the means of acquiring it.

The Elements

The matter of which the earth and its waters and atmosphere are made is divisible into elements that have distinct chemical properties. Elements are the 'building blocks' of minerals and, in turn, minerals are the 'building blocks' of rocks. The 103 elements that have been identified and named are listed in Appendix I, together with the symbols that are used to identify them in chemical formulas. Some elements are abundant, some are moderately so, and some are rare. All the elements have probably now been discovered with the possible exception of unstable ones formed in a laboratory. Some elements exist by themselves in nature, but most are in combinations of two or more different elements. These combinations are called chemical compounds, and as there are more than 100 elements it is easy to understand why the number of different combinations is very large. The atoms of each element have distinct characteristics, and one or more atoms of one element may combine with one or more atoms of another. For example, two atoms of hydrogen combine with one of oxygen to form water; to express this the formula of water is written H_2O.

Two kinds of elements are of direct interest to prospectors: metals and non-metals. The metals are opaque to light, have a shiny 'metallic' appearance, generally can be deformed by hammering, and are conductors of heat and electricity. The non-metallic elements include the gaseous elements and such solid ones as sulphur, carbon, and silicon, which do not have metallic properties. A few elements like arsenic and antimony are called semi-metals or metalloids because they have some of the properties of both metals and non-metals.

The Nature of Minerals

A mineral is an element or, more commonly, a chemical compound of two or more elements occurring in the earth. More precisely, a mineral is a naturally occurring, homogeneous, inorganic substance with a characteristic chemical composition and fairly definite physical properties. The phrase 'naturally occurring' is included to distinguish between minerals and synthetic compounds produced by man. Minerals are homogeneous, so that any fragment of a particular mineral normally has the same composition as any other fragment of the same mineral. Minerals are inorganic, so such things as bones, shells, pearls, and other organic materials are excluded, both because of their origin and because they do not have a homogeneous molecular structure. Mercury is classed as a mineral because it is a liquid metal. Even water, strictly speaking, is a mineral because it has a definite chemical composition and, particularly in the form of ice, a definite crystal structure. Petroleum and coal, on the other hand, are not strictly classed as minerals because they are variable mixtures of several chemical compounds; the petroleum and coal industries are, however, classed as parts of the mineral industry.

The Classification of Minerals

By long-established custom minerals are classified basically according to their chemical composition and are divided into groups such as native elements (gold, diamond, etc.), sulphides (compounds with sulphur, such as pyrite, which is iron sulphide), oxides (compounds with oxygen, such as uraninite, which is uranium oxide), carbonates (compounds with carbon and oxygen, such as calcite, which consists of calcium, carbon, and oxygen), and several more complicated groupings. Classified by this system, the total number of known minerals is about 2,000.

Certain elements or compounds are intermixed with others and form what are called 'solid solutions', or 'series', in which separate mineral names are applied according to arbitrary limits placed on the amount of a particular element or compound present. For example, silver forms a solid solution with gold, thus accounting for the fact that most gold mines produce silver as a byproduct although no distinct silver minerals occur in the ore; minor amounts of contained silver do not prevent the mineral from being classed as gold, but if substantial amounts of silver are present the mineral is called electrum. A common example of compounds occurring in a series is the group of minerals called plagioclase feldspars, to which separate names are applied according to the percentages of sodium or calcium compounds present. Slight variations also may occur in minerals because certain elements or groups of elements,

having more or less the same properties as one of the essential components of a mineral, may be substituted for it in the crystal structure of the mineral. In this way small amounts of manganese may occur, taking the place of some of the iron in an iron mineral without changing its classification; many other such examples could be mentioned.

Many minerals are impure because small masses of another mineral occur within them as tiny bodies called *inclusions* or as minute veinlets. Many of these are so small that they cannot be seen except with the aid of a high-power microscope.

Apart from the basic chemical classification of minerals, it is often convenient to classify them in other ways. For instance, minerals may be spoken of as being metallic or non-metallic according to whether or not they display a metallic shine or *lustre*. It should be noted that this refers to the appearance of the mineral itself, not to the content of the mineral, because many minerals that contain important amounts of a metal do not have metallic lustre. If a metallic mineral is powdered or is scratched across a piece of unglazed porcelain the powder or 'streak' is invariably darker than the solid mineral. When distinguishing between minerals that yield metals and those that do not, the terms 'metalliferous' and 'non-metalliferous' are commonly used in geological literature. In statistical and economic literature, however, the terms 'metallic' and 'non-metallic' are often used in the same sense as 'metalliferous' and 'non-metalliferous'.

Minerals are also designated as 'primary' or 'secondary'. These are in some ways useful terms but they may cause confusion. The normal use of the terms implies that primary minerals are in the state in which they were originally formed, and that secondary minerals are the result of alteration of primary minerals by such processes as oxidation. Many minerals when exposed to moisture at or near the land surface are altered to secondary minerals in much the same way as a piece of iron rusts. The latter kind of secondary minerals may form large deposits, some of which are mined, but more commonly they form a crust or 'bloom' that occurs in small quantities but which may be an important clue for prospecting because it attracts attention and may lead to the discovery of a deposit of primary minerals (*see* Chap. 4). Minerals produced by metamorphism as explained in Chapter 2 may also be considered secondary; therefore a less ambiguous term for minerals produced by oxidation and other near-surface processes is *supergene*.

The Identification of Minerals

Although minerals are classified chemically, they can be identified in several ways other than by chemical tests or analyses, such as by their colour, weight, hardness, or crystal form. For a few minerals one such characteristic permits a definite identification. For a number of others, two or three simple tests are sufficient. Thus, by sight or simple tests that can be made in the field or at home, a specialist in mineralogy can identify a few hundred minerals, and non-specialists can identify fewer. Most other minerals can be identified positively only by extensive laboratory work that may take the form of microscopic examination, complicated chemical procedures, measurements of crystals, or X-ray photographs that determine the internal crystalline structure. Fortunately, most such minerals are rare and not of great importance in prospecting; most of the principal ones can usually be identified fairly readily. It is not essential for a prospector to be able to identify many minerals, for, if he knows what ores look like in general, he can send samples for assay, but he should know at least fifty or one hundred of the more important minerals.

Simple chemical tests for some elements can be made in camp or at home, some requiring the aid of a blowpipe to produce a hot flame from a candle or lamp. Portable kits for some tests can be bought from dealers, or the individual items can be bought separately. For some tests discarded tumblers, cups, or saucers will serve instead of the usual chemical ware. Care must be taken to have the vessels clean and to keep the chemicals away from children and food supplies. A magnifying glass or 'hand lens' is useful for examining specimens. Introductory information on the identification of minerals and on chemical tests is included in Appendix VI for those who desire it.

Acquiring Further Knowledge

The foregoing gives only the barest introduction to mineralogy. The best way to gain further knowledge or to refresh what one had once learned is to attend one of the courses available in several parts of Canada. Information about these is given in Chapter 6. If it is impossible to attend a course, one can obtain books intended for self-instruction, some of which are listed at the end of this section. Study of such books should be supplemented by actually handling and testing specimens. Sets of minerals and rocks are obtainable from the Geological Survey of Canada* and, it is understood, from some provincial mining departments. Specimens can also be bought from dealers.† Minerals should, if possible, also be studied in natural outcroppings, where the weathered appearance is commonly different from that of the freshly broken specimens avaliable for study in courses or at home. Specimens from, or outcrops of, actual mineral or ore deposits (*see* Chap. 4) should be studied if possible, because they commonly differ from mineral specimens, as they are mixtures of minerals or of minerals and rock.

If one attends a course, minerals for study and methods of identification will be recommended. For those who wish to learn by themselves, Appendix IV lists the principal minerals and some others, with notes on their chief characteristics. For the field, or other purposes, separate copies of this table are available from the Queen's Printer, Ottawa, at small cost. A prospector will benefit from learning to recognize more minerals than are listed in this table, and he may also make a hobby of collecting and identifying unusual minerals. He should remember, however, that his main objective is to find useful minerals in mineable quantities.

* At the time of writing, these are as follows: a set of 36 common minerals at $2 per set; a set of 36 common rocks at $2 per set; and a set of 120 minerals and rocks at $25 per set.

† A list of several dealers in Canada is obtainable from The Director, Geological Survey of Canada, Ottawa, Ontario.

Suggestions for Additional Reading

Dana, E.S.
1949: Revised by C.S. Hurlbut, Jr.: Minerals and how to study them, 3rd ed.; New York, Wiley and Sons.

Hewitt, D.F.
1964: Rocks and minerals of Ontario; Ontario Department of Mines, Geol. Circular 13.

Howie, R.A.
1967: Current trends in mineralogy; *Earth Sci. Rev.*, vol. 3, pp. 31–46.

Miller, W.G.
1928: *Revised by* Parsons, A.L.: Minerals and how they occur, 2nd ed.; Copp Clark Co., Ltd., Toronto.

Pough, F.H.
1955: A field guide to rocks and minerals, 2nd ed.; Houghton Mifflin Co., Boston.

Trail, R.J., *et al.*
1962: Raw materials for Canada's mineral industry; *Geol. Surv. Can.*, Paper 62-2.
Consists of descriptions to accompany the larger set of mineral and rock specimens sold by the Geological Survey of Canada.

Vauders, I., and Kerr, P.F.
1967: Mineral recognition; New York, Wiley and Sons.
A fairly expensive but excellent book for non-professional readers.

ROCKS

Rocks form fairly large units of the earth's surface. The distinction between minerals and rocks is that minerals are homogeneous substances that exist as crystals or grains, whereas almost all rocks are aggregates of mineral grains or crystals. A few kinds of rock such as volcanic glass, however, are not granular. Most rocks are mixtures of two or more minerals, but a few consist of grains of only one mineral; examples of the latter kind are pure sandstone, composed of quartz, and pure limestone, composed of calcite. A few special rocks, such as coal, consist of organic matter that is not a mineral by strict definition.

Rocks are divided into three main classes called *igneous*, *sedimentary*, and *metamorphic*. The origins of igneous and sedimentary rocks were explained in the previous chapter. The characteristics and classifications of the principal kinds of igneous, sedimentary, and metamorphic rocks are discussed here. The origin of metamorphic rocks was not mentioned previously because they are a special class. They are formed from igneous or sedimentary rocks by changes in temperature or pressure, or both, which took place deep in the earth's crust and resulted in the rearrangement of elements to form minerals that were more stable under these changed conditions. Some rocks of the general metamorphic class contain minerals formed partly by the addition of elements to pre-existing rocks, by processes causing diffusion of elements.

Geologists use two kinds of classifications for rocks, one of which can be applied in the field by ordinary observation or with a pocket lens. The other, more detailed, classification can normally be applied only after laboratory studies, such as examination with a microscope or chemical analyses, have been performed. Field classifications suffice for most prospecting and for understanding the essentials of most geological reports, therefore they are the only ones discussed below. Although the main types of igneous, sedimentary, and metamorphic rocks are well established, many varieties grade into one another; therefore, many 'border line' examples are found.

Igneous Rocks

Almost all igneous rocks are crystalline, although most have an interlocking rather than a crystalline texture because of the almost simultaneous growth of grains from the cooling magma. Under special cooling conditions, however, well-shaped crystals develop. If these are larger than the remainder of the rock they are called *phenocrysts* and the rock is a *porphyry*.

In most igneous rocks the common rock-forming mineral is one of the feldspar family of minerals, generally accompanied by smaller amounts of quartz. These minerals are generally light in colour. Other important rock-forming minerals are those containing iron and magnesium, called ferromagnesian minerals, such as hornblende, pyroxene, olivine, and biotite; these minerals are dark. There are also many 'accessory' minerals, such as magnetite, which occur in almost any kind of igneous rock in small amounts that do not affect the classification. Igneous rocks composed mainly of feldspar and quartz are commonly called *acid rocks*, and rocks lacking quartz and containing much ferromagnesium material are *basic*. These are unfortunate terms because they are widely used in another sense in chemistry. More appropriate terms are *siliceous* or *felsic* for rocks containing much quartz or feldspar, and *femic* or *mafic* for the ferromagnesian rocks.

Separate classifications (*see* table in Appendix V) are used for the coarser grained plutonic rocks that form stocks and batholiths, and for the finer grained rocks that form dykes, sills, and flows of volcanic rock. The compositions of coarser and finer grained rocks are commonly related because they originated from the same source, but the grain-sizes and textures differ because of the more rapid cooling of dykes, sills, and flows. Volcanic rocks commonly exhibit banded and other *structures* resulting from the flowage of the molten material. Use of the word structure for these internal characteristics must not be confused with its use for large-scale structures such as folds and faults.

Plutonic Rocks

In these relatively coarse textured rocks, as in granite, the grains can generally be seen with the unaided eye. Plutonic rocks are classified primarily according to the amount and kind of feldspar and the amount of quartz or ferromagnesian minerals they contain. The general kind of feldspar present can commonly be estimated by the unaided eye or with a hand lens, but for some rocks this is difficult or impossible. In detailed studies these groups are further subdivided into numerous varieties based on microscopic or chemical studies. For field purposes it is sufficient to use the following distinctions.

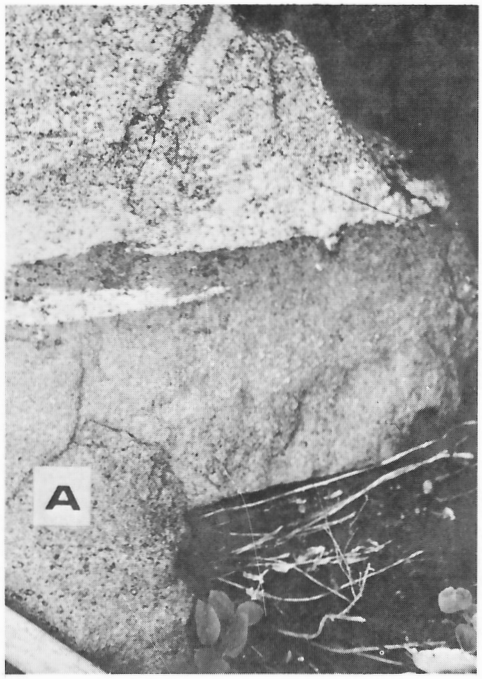
Granite is a relatively light coloured rock composed of potash feldspar and quartz. Many granites also contain relatively small amounts of white mica, biotite, or hornblende. If the rock contains relatively large, well-formed crystals scattered in a matrix of ordinary granitic material, it is called *granite porphyry*, and so on for the types described below.

Syenite is a light coloured rock composed mainly of potash feldspar. Little or no quartz can be seen, even with a lens.

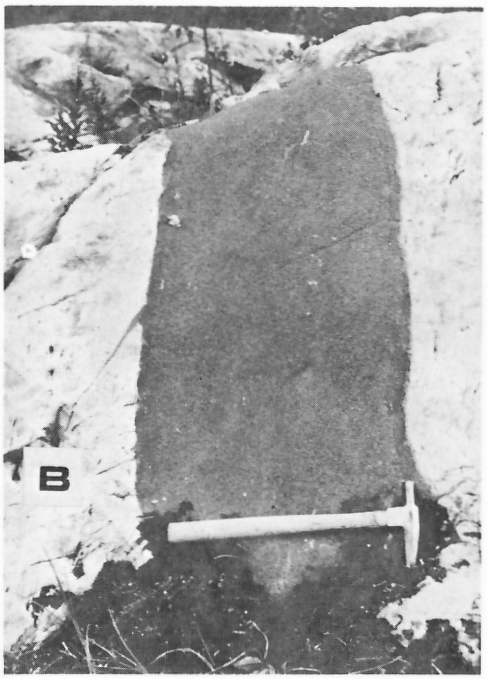
Diorite is a fairly dark coloured rock composed mainly of plagioclase feldspar, with considerable amounts of one of the amphibole family of minerals — commonly hornblende — or one of the pyroxene family. Other common types are *granodiorite*, containing appreciably more plagioclase than potash feldspar, and *quartz diorite*, containing more than 10 per cent quartz.

Gabbro is a dark coloured rock composed mainly of calcic rather than sodic plagioclase, commonly labradorite, with large amounts of amphibole or pyroxene. With decreasing amounts of ferromagnesian minerals, gabbro grades into *anorthosite*.

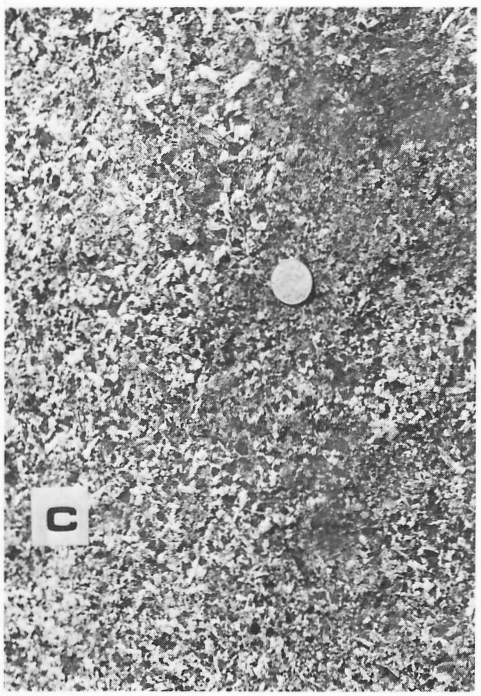
Ultramafic rocks consist almost entirely of the ferromagnesian minerals olivine or pyroxene or both, with little or no plagioclase. They are generally altered to serpentine minerals. They characteristically weather an orange-buff colour and have dark green to black fresh surfaces. Magnetite formed during alteration to serpentine causes the rock to be weakly to moderately magnetic.



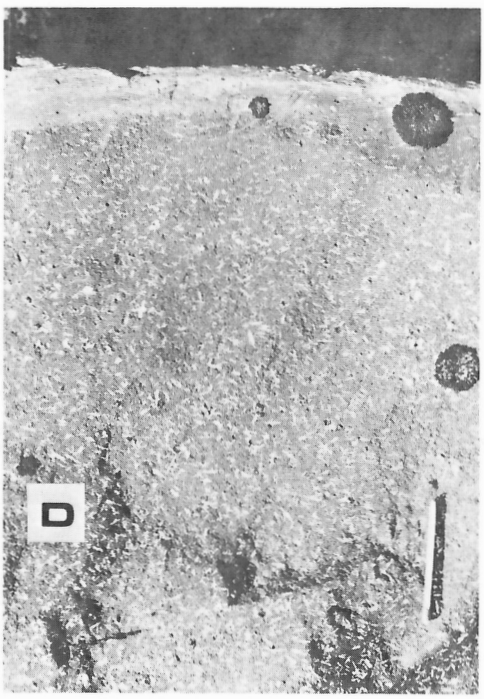
H. M. A. Rice 85469



J. W. Ambrose 83039



B. W. H. Norman 82236



C. S. Lord 88142

Plate 24

A. Diorite (lower) intruding granite (upper). Note the finer grained texture of the diorite close to the granite, caused by chilling against it.
B. Trap dyke with chilled margins intruding granite.
C. Diabase, coarser grained than usual.
D. Dyke of feldspar porphyry.

Rocks of Dykes and Sills

These are commonly finer grained than their plutonic equivalents but some, such as many diabases and pegmatites (explained below), are coarse grained. Equivalents to the main classes of plutonic rocks are given in the table for igneous rocks in Appendix V. Other common types are aplite and diabase. *Aplite* is a fine-grained, evenly textured rock equivalent to granite in composition and commonly displaying a sugary appearance. *Diabase* is a rock nearly equivalent in composition to gabbro, commonly having a characteristic arrangement of lath-shaped crystals, called diabasic texture (*see* Pl. 24C).

Besides occurring as even-textured rocks, many of the classes of rock mentioned above may be porphyries. They are usually named according to the composition of the phenocrysts; common examples are *quartz porphyry*, *feldspar porphyry*, and *hornblende porphyry*.

Another common kind of dyke rock is *pegmatite*, a coarse-grained rock formed under special conditions that permitted the growth of large mineral masses or crystals. The commonest examples are granite pegmatites, composed essentially of large masses of feldspar and quartz, from about half an inch to a foot or more in diameter; they may also contain crystals of mica, apatite, and many other minerals. More rarely, pegmatites are encountered whose compositions correspond to syenite, diorite, or gabbro.

The rocks of dykes and sills, and volcanic rocks, may be too fine grained to permit field determination of the constituent minerals. In such cases the general terms *felsite* and *trap* are used for light and dark coloured rocks, respectively.



G. Shaw 86105

A. Pegmatite dyke intruding schist.

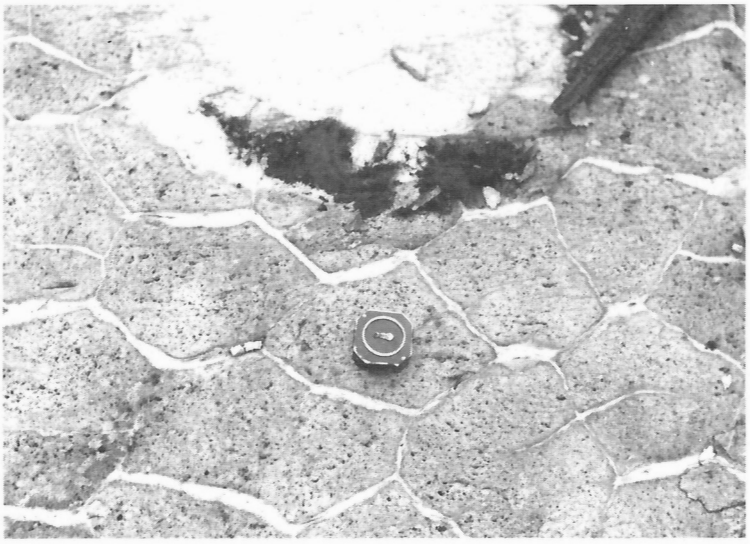


H. M. A. Rice 85473

B. Pegmatite dyke intruding sandstone (dark grey). The dyke has been faulted, and an aplite dyke, marked by the hammer-head, was afterwards intruded along the fault.

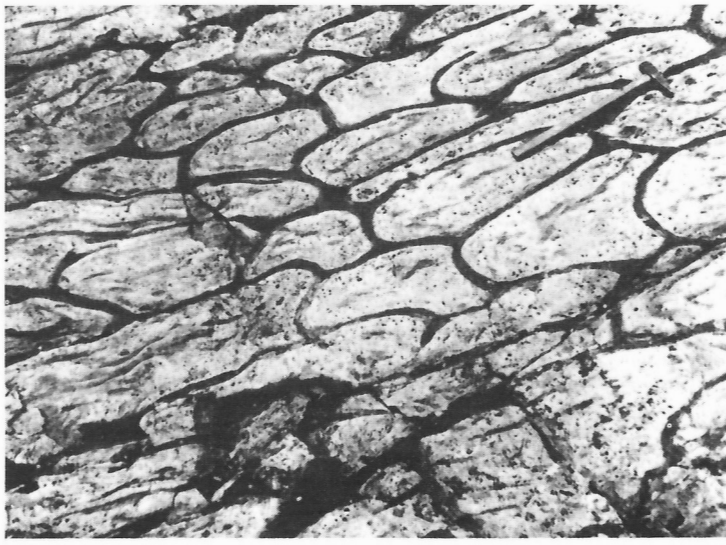
Plate 25

C. Rhyolite containing polygonal fractures filled by small veins. Such fractures are caused by shrinkage of the lava during cooling.

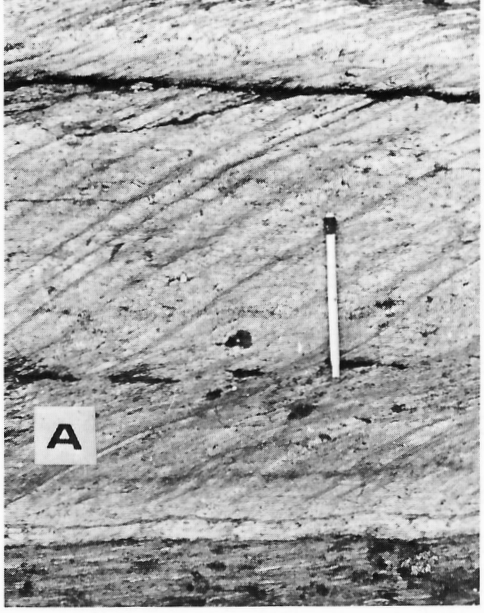


J. W. Ambrose 84901

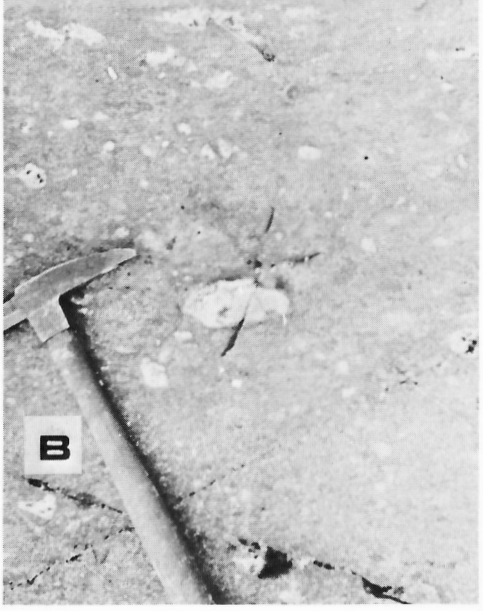
D. Pillows in greenstone.



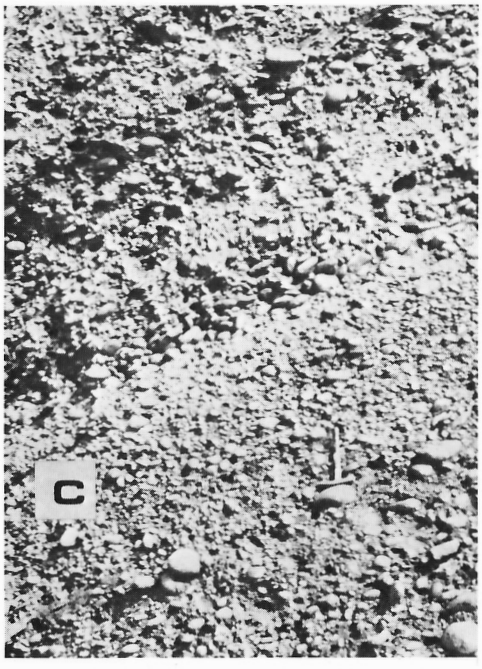
J. F. Henderson 84169



A. F. Buckham 87148



A. W. Jolliffe 84425



F. J. Alcock 81569



J. G. Gray 85394

Plate 26

A. Fracture cleavage in a bed of tuff. Note that the bedding is horizontal, and the cleavage developed by pressure is at about 45 degrees to the bedding.
B. Volcanic breccia or agglomerate, overlain by tuff.
C. Relatively young (Triassic) conglomerate in which the matrix weathers away, freeing the pebbles and cobbles. In older conglomerates, such as those of Precambrian age, the matrix is usually recrystallized so that it and the pebbles form a hard rock that weathers or fractures across the pebbles instead of around them.
D. Fractures in sandstone. Note the three directions of fracturing.

Volcanic Rocks

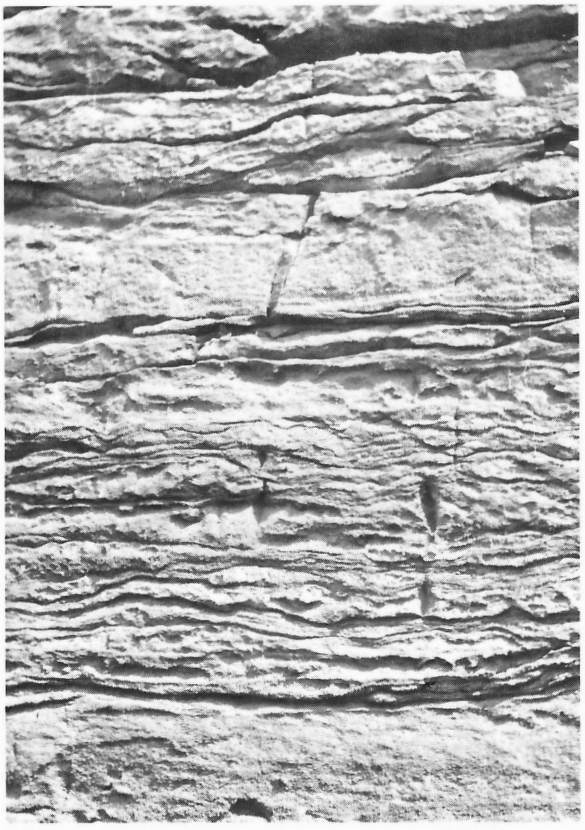
Volcanic rocks correspond in composition to one type or another of plutonic rock, but tend to be fine grained or glassy and to have distinct structures which are described below. Their fine grain-size makes it sometimes difficult to recognize the constituent minerals and to name the rock, although the general colour may be of some assistance. Volcanic rocks may be even textured or porphyritic. The latter are usually named according to the kind of rock, and may be called by such names as rhyolite porphyry or andesite porphyry, but they may also be classed according to the kind of phenocrysts and be called by names such as quartz porphyry or hornblende porphyry. Many volcanic rocks contain small holes (vesicles) left by gas or steam and are termed *vesicular*. If some or all of the vesicles are filled by a later-formed mineral the rock is said to be *amygdaloidal*. Volcanic rocks of basaltic or near basaltic composition (*see* Appendix V) are commonly segregated into pillow-shaped masses caused by flowage under water or at least in a very wet place.

Rocks that are in one sense volcanic and in another sedimentary are formed as a result of volcanic explosions that shatter material which had crystallized in the throat of a volcano, causing ejection into the air of large angular fragments, or small fragments that form volcanic ash. When material of these kinds falls to earth it may be deposited in layers on dry land or in bodies of water, and later become rocks. Those containing large fragments are named *volcanic breccia* or volcanic agglomerate, and the finer grained ones are called *tuff*. They are distinguished according to their compositions, as rhyolite tuff, andesite breccia, etc.



C. S. Lord 85518

A. Shale, of a variety a little harder and more slabby than usual.

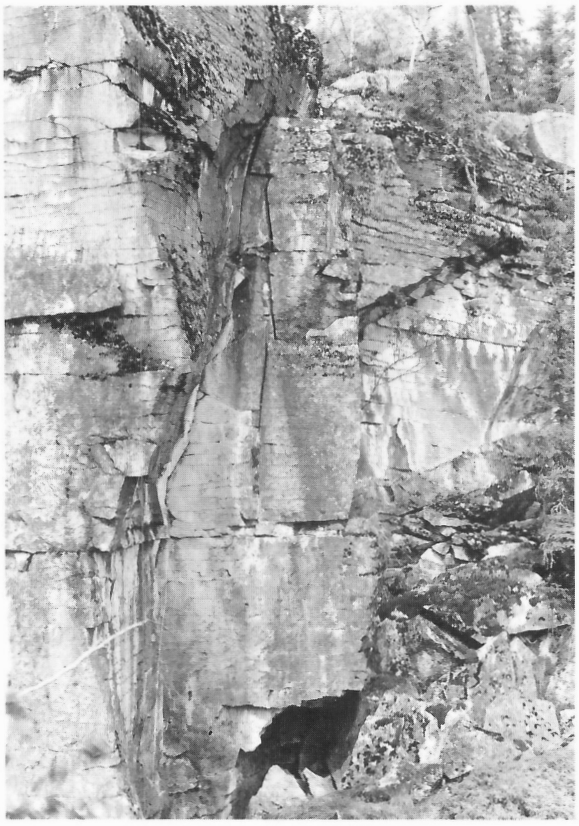


H. Gauthier 41141

B. Limestone, showing irregular weathered surface caused by variations in composition of the rock.

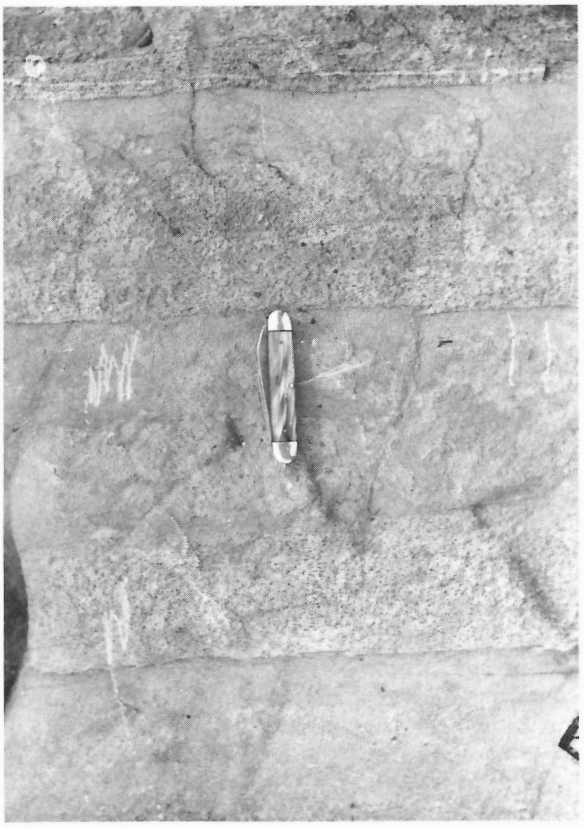
Plate 27

C. A cliff of dolomite. Outcrops of limestone may have a similar appearance.



T. L. Tanton 85872

D. Coarse and fine greywacke, interbedded.



H. C. Gunning 81953

Sedimentary Rocks

The processes by which sediments are produced by erosion and deposited on dry land or under water have already been discussed. Such sediments become gradually compacted by the weight of overlying material, and the grains may be cemented together by silica, calcium carbonate, or other compounds crystallized from impurities dissolved in water that percolates between the grains. In these ways sediments become solid sedimentary rocks, which are classified according to the size and composition of their grains.

The coarsest sedimentary rocks are conglomerate, tillite, and sedimentary breccia. *Conglomerate* is formed from gravels containing pebbles, cobbles, or boulders. *Tillite* is a special type formed from unsorted glacial debris (till). Sedimentary *breccia* is composed of angular fragments of rock such as are found in rock slides and talus slopes. Rocks composed of small particles no larger than peas, but not as small as sand, are called *grit*.

Rocks formed by the consolidation of sand are among the commonest of sedimentary rocks. Fairly pure sand composed almost entirely of quartz grains forms *sandstone*. If the grains are very small the rock is called *siltstone*. If grains of feldspar are fairly abundant the rock is *feldspathic sandstone*, but if feldspar predominates, it is *arkose*. Sands containing large amounts of ferro-magnesian minerals as well as feldspar, such as result from erosion of diorite or gabbro, produce *greywacke*. Sands deposited at the same time as volcanic activity took place nearby are commonly mixed with volcanic ash, and when consolidated they form such rocks as *tuffaceous sandstone* or *tuffaceous greywacke*.

Finer grained sediments, chiefly muds and clays, produce *shales*. These are generally thinly bedded grey or black rocks that are fairly soft and brittle; small slabs that are easily detached from outcrops can usually be broken between two fingers.

Most water, whether fresh or sea, contains considerable calcium carbonate in solution, along with other chemical compounds. Under favourable chemical conditions these compounds are expelled from solution to form soft sediments that may become hardened into rock. *Limestone*, formed from calcium carbonate, is the commonest of such sedimentary rocks. It is fairly soft, generally white or grey in colour, although it may be black, and its weathered surfaces commonly have a characteristically rough and pitted appearance as calcium carbonate is slowly soluble in rain or other water. Some limestones, particularly if impure, are difficult to identify by eye but they effervesce readily if a drop of weak acid is applied. Almost as common as limestone is *dolomite*, composed mainly of magnesium carbonate. Dolomite resembles limestone, but can usually be distinguished from it because it does not effervesce readily when weak cold acid is applied; if a little of the rock is powdered or scratched with a knife, it will effervesce.

Metamorphic Rocks

Igneous or sedimentary rocks may be changed to entirely different types, called *metamorphic* by the action of pressure, heat, and to some extent by the introduction of material in fluid or other states. These changes take place fairly deep in the earth's crust, but the resulting rocks may be found at or near the surface as a result of deep erosion. Metamorphism may cause recrystallization of the original rock-forming minerals in grains of different size or orientation, or the formation of new minerals that are more stable under the changed physical or chemical conditions.

The word 'metamorphism' means literally 'change of form'. In some early usages the term was restricted to changes by heat or pressure, without significant introduction of material. Modern usage excludes weathering and regards metamorphism as resulting mainly from heat or pressure, or both, but also to some extent from introduction of material by solutions or gases. More extensive exchanges of material are classed as metasomatism and granitization, as explained elsewhere.

Metamorphism results in partial or complete reorganization of the minerals of a rock to form a new assemblage of minerals; in changes in the grain-size of minerals, generally to coarser textures; and, commonly, in new rock structures, particularly those in which minerals are aligned in parallel foliations or bands. Common metamorphic minerals are micas, garnet, staurolite, kyanite, and sillimanite. Some rocks are so metamorphosed that their original types are difficult or impossible to determine. Identification may be aided if patches of relatively unaltered rock are found, or if a stratum or other body such as a dyke can be traced into its unmetamorphosed or relatively unmetamorphosed equivalent.

Some geological reports refer to *contact* and *dynamic* metamorphism. The former refers to more or less local metamorphism around a body of intrusive rock, and the latter to metamorphism of large bodies of rock, commonly related to orogenic pressures.

Some of the more common metamorphic rocks are defined briefly as follows:

Marble: a recrystallized rock composed mainly of the minerals calcite or dolomite, and derived from limestone or dolomite.

Skarn: a medium- or coarse-grained rock composed mainly of lime–silicate minerals and commonly containing magnetite.

Serpentine: a rock composed almost entirely of minerals of the serpentine–chlorite family. The colour is commonly green to black.

Greenstone: a field term for greenish rocks, generally composed mainly of chlorite, amphibole, or epidote. They are commonly derived from volcanic or plutonic rocks of intermediate to basic composition

Quartzite: when used to describe a metamorphic rock this term is applied to rocks composed mainly of quartz, having an irregular fracture that tends to break across

individual grains rather than around them. The term is also used for well-cemented sandstone composed mainly of quartz.

Fenite: a special kind of contact metamorphic rock associated with alkaline igneous rocks.

Argillite: a hardened mudstone without slaty cleavage.

Slate: a recrystallized shale characterized by good cleavage, and lacking the coarser grain-size of phyllite.

Hornfels: a recrystallized rock of fine or medium grain produced by contact metamorphism, without schistosity or slaty cleavage; commonly formed from slate or related rocks.

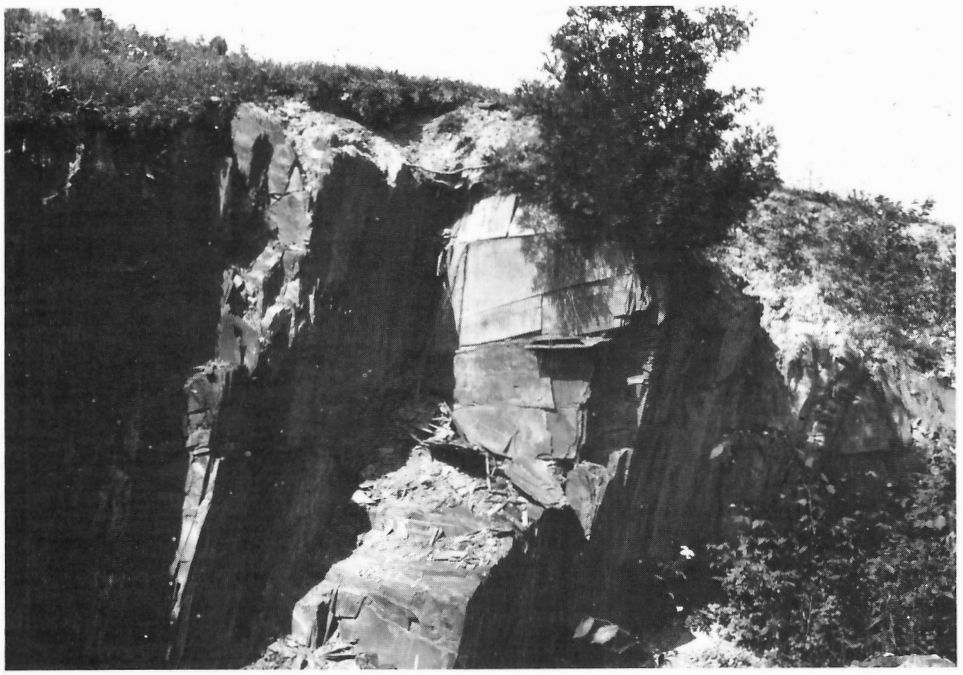
Phyllite: a rock intermediate between slate and schist in grain-size and metamorphic grade, in which abundant chlorite and mica cause foliation approaching that of schist.

Schist: a markedly foliated rock composed mainly of platy minerals such as mica or chlorite, as well as granular minerals such as quartz, feldspar, or garnet. Various types may be described as biotite schist, garnet schist, etc.

Greenschist contains abundant green minerals such as chlorite, hornblende, or epidote.

Gneiss: a more or less granular rock characterized by alternate bands of light and dark coloured minerals, such as

Plate 28



T. H. Clark 74389

A. Slate. Note that the cleavage, or direction in which the rock tends to split, is approximately parallel with the plane of the photograph, whereas the bedding is parallel with the left side of the quarry.



C. K. Bell 119969

B. Sedimentary gneiss containing "knots" of garnet, Canadian Shield.

quartz, feldspar, biotite, and amphibole. The directions of easiest fracture may be parallel with or across the layering, but parallel cleavage is less regular than that in schists. Gneiss derived from igneous rocks may be called *orthogneiss*, and that from sedimentary rocks *paragneiss*, but such distinctions are not always possible. A common type of orthogneiss is granite gneiss, but the term is sometimes used misleadingly for rocks that only appear to have been derived from granite.

Special classes of gneiss, which are related, are *hybrid gneiss*, a mixed gneiss composed partly of older metamorphic rock and partly of igneous material; *lit-par-lit* gneiss, a mixed gneiss with regular alternation of granitic and mafic layers; and *migmatite*, a mixed rock commonly but not necessarily gneissic, composed of granitic material and presumably older, metamorphic parts.

Amphibolite: a rock of medium to coarse grain composed essentially of amphibole and plagioclase.

Granulite: a medium- to coarse-grained rock, with granular texture and little or no foliation.

Eclogite: a dull greenish, granular textured rock composed of pyroxene and garnet.

Metamorphic rocks may be described as *low grade* or *high grade* depending on the degree of metamorphism undergone by the original rocks, and more particularly on the effects of heat. The subject of metamorphic grade



J. W. Gillis 119100

Plate 29

A. Contorted granite gneiss, Newfoundland.



C. K. Bell 117909

B. Lit-par-lit gneiss, Canadian Shield.

has been extended into the concept of metamorphic *facies*, whereby all the rocks within a certain temperature–pressure range are characterized by certain minerals or rocks that are stable for that range, although other rocks may occur in the facies as well. This is an important study for geologists dealing with metamorphic rocks. It is not necessary for prospectors to be able to recognize all the rocks involved, but a general knowledge of the subject will aid in the understanding of many reports, particularly those for parts of the Canadian Shield. A fairly simple table has, therefore, been included in Appendix V.

Concluding Advice on Rocks

Most of the commoner rocks have been mentioned at least briefly in the last few pages. Many additional rocks can be found in the field or are referred to in geological reports, because there are many special types or 'borderline' examples. It is not necessary for a prospector to be able to recognize all the types described in this chapter but knowledge of as many as possible is a great aid in prospecting and in understanding the literature. In many mining districts special rock types are important because of their relation to ore occurrences; some of the names used for them are local jargon. A prospector working in such a district should familiarize himself with the rocks concerned, which may be possible only after he has reached the district.

One cannot learn to recognize the common rocks merely by reading about them. The best way is to attend a course, where instruction and specimens will be provided. If this is not possible a person can locate occurrences by studying a geological map of the area he happens to be in. Tables to assist in the recognition of the common rocks form Appendix V, but the serious student of prospecting who cannot attend a course will be well advised to use one or more of the books on rocks listed below as additional aids to his study of specimens. He should also familiarize himself with the appearance of rocks as they occur in the field, because specimens in sets or courses almost always exhibit only fresh surfaces. Outcrops are weathered, their outer parts being commonly quite unlike the fresh rock that is sometimes difficult to expose even after considerable picking or hammering. Also, some kinds of rocks are easier to recognize from a weathered outcrop than from a fresh surface. For these reasons the illustrations in this chapter are from photographs of outcrops, not specimens.

Suggestions for Additional Reading

Pirsson, L.V.
1947: Rocks and rock minerals; 3rd ed.; New York, Wiley and Sons.

Spock, L.E.
1962: Guide to the study of rocks; 2nd ed.; New York, Harper and Bros.

NOTE. Some of the books listed at the end of the section on minerals also include information on rocks.



4 mineral deposits

Prospecting is searching for mineral deposits that have some chance of being commercially valuable; therefore prospectors need a sound, practical knowledge of the nature of mineral deposits. These are of many kinds, shapes, associations, and origins, the essentials of which are not difficult to learn. Their detailed definitions, classifications, and theories of origin, which are mainly beyond the scope of this book, are complicated, and sometimes confusing because different writers use some terms in partly different ways. The first sections of this chapter explain the main, non-theoretical ways in which deposits are described and classified. The chief terms needed for understanding later parts of this book and other publications on mineral deposits are introduced. These sections cover most of the topics needed for understanding later chapters. The second part discusses briefly the facts and theories of the origins of deposits, and the last contains short descriptions of several types of deposits with which prospectors might be concerned, particularly in Canada. The second and last parts of the chapter may not be required by some readers, but others may find it useful for further study.

Mineral deposits are classified in different ways, all of which are useful for particular purposes. Deposits are classified according to their importance, according to the products (commodities) for which they are or may be valuable, according to their shapes or forms, and in other ways explained later. Several such methods of classification are commonly used when referring to a particular deposit. For example, a deposit may be called a 'producing, gold–copper quartz vein in granite'.

PRACTICAL CLASSIFICATIONS OF DEPOSITS

Considerations of Value or Importance

Small concentrations of one or more minerals are usually called *mineral occurrences*. A *prospect* is an occurrence large and rich enough to have some promise of being, but not yet proven to be, an ore deposit. An *ore deposit* is one that can be mined under present conditions, at profit to the operator or to the benefit of a country, unconsolidated deposits and mineral fuels usually being excluded from this definition. The term *mineral deposit* is usually considered to be a more general term than 'ore deposit' and to include prospects and ore deposits; in a more general sense, such as in the title of this chapter, it includes occurrences. Unconsolidated deposits and concentrations of mineral fuels are considered to be kinds of mineral deposits. A *mine* is usually regarded as an opening or excavation from which ore, valuable unconsolidated material, or coal is obtained, but open excavations for such products as sand and gravel are called 'pits' and those for stone, 'quarries'. In popular language, prospects that are being or have been tested are often called mines, but this is incorrect even if the testing includes a shaft or adit (tunnel).

Ease of Discovery and Testing

The relative ease or difficulty of recognizing and testing deposits — and also mining them — is of much practical significance. On this basis, deposits can be classified in the following way, although some borderline examples are inevitable.

1. *Deposits with conspicuous outcrops.* Some deposits that outcrop (apex) at the surface contain minerals that are easily recognized as having possibilities if the deposit is sufficiently large and has sufficient mineral content. Tests to obtain that information are relatively easy because the outcrop or nearby outcrops may be sufficiently extensive to permit testing, or at least will indicate where testing should be done beneath overburden. These considerations would apply also to a well-exposed unconsolidated deposit except that the word 'outcrop' would not apply. If mining is undertaken the presence of outcrops would make the beginning of mine openings easier than if overburden must first be removed.
2. *Deposits with inconspicuous outcrops.* Many mineral occurrences are so small as to be inconspicuous. Experience shows that such occurrences occasionally are the only outcropping part of a larger deposit that is almost completely hidden, or are a sign of a completely separate, nearby deposit that does not outcrop. Other causes of inconspicuous outcrops are the low mineral content of some large, workable deposits and the similarity in appearance of some useful minerals to ordinary rock-forming minerals. The discovery and judging of deposits outcropping in any of these ways requires more skill and experience on the part of conventional prospectors than do deposits of the first category; they may be beyond the scope of conventional prospecting.
3. *Buried deposits found by testing the vicinities of known orebodies.* Many deposits have been found in established mining camps by the study, first, of the geological conditions known or believed to be responsible for the occurrence of one or more of the known orebodies, and then by the application of that information to similar rocks, structures, or other conditions in other parts of the area. In recent years, such searching has commonly been aided by geophysical or geochemical surveys. Searches of this kind are virtually beyond the scope of conventional prospecting, if for no other reason than that such areas are usually completely staked.
4. *Deposits covered by overburden.* The upper parts of

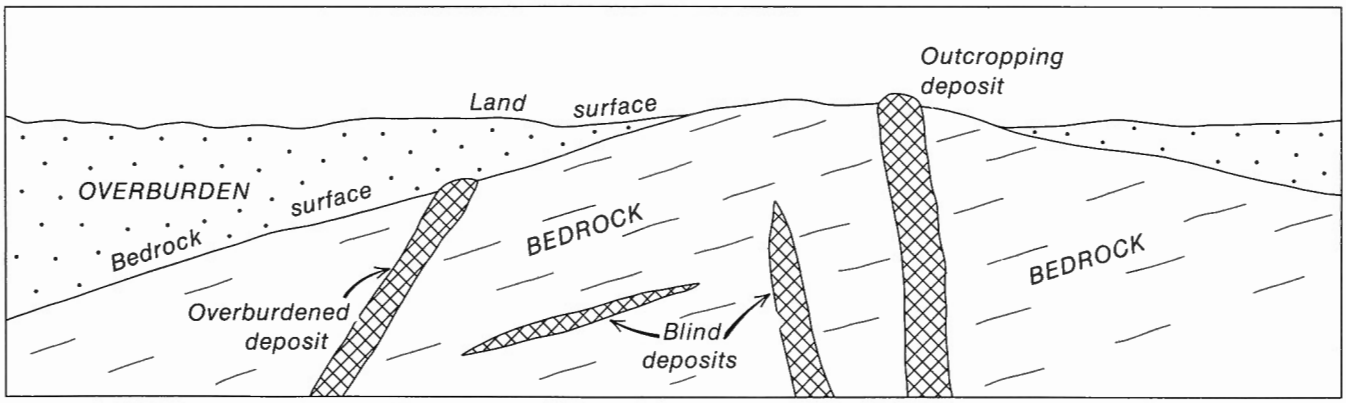


Figure 5. Outcropping mineral deposit, and deposits obscured by overburden or bedrock.

many deposits reach the bedrock surface but are covered entirely by overburden. Overburdened deposits apexing in this way are much more difficult to discover but are a main objective of modern advanced prospecting; if the overburden is shallow the deposits may be within the scope of conventional prospecting.

The need for a recognized term to apply to this condition is increasingly evident. Some writers call deposits covered by overburden 'sub-outcrops' but this is illogical because 'outcrop' implies cropping out at the surface of the land. 'Overburdened deposit' or 'overburdened apex' are suggested as more suitable terms.

5. *Deposits that do not reach the bedrock surface.* Some deposits have been discovered although covered completely by host-rock. Many more are doubtless present. Because such deposits are now receiving more attention as targets for advanced prospecting, agreement on a general name for them is needed.

The term 'blind' has long been used in mining jargon for a vein or lode that does not outcrop. Standard references are unclear as to whether overburdened apexes are included, but the term seems to have been used at least mainly for veins that apexed in rock. The writer suggests that it be restricted to deposits covered by rock and that it be used for concordant as well as transgressive deposits, which are explained later.

6. *Potential ores.* In this category are known or partly tested deposits whose content or size is somewhat below the standards of those required under present demands, mining costs, treatment methods, or transportation facilities. The term 'protore' is sometimes applied to deposits of potential ore that are well tested and not far below present commercial grades.

7. *Ultra low-grade deposits.* These are deposits ranging between common rocks and what are at present classed as potential ores. They may be used in future under greatly changed conditions.

Commodity Classifications

For many purposes, including general statistical and reference material, the most suitable classifications are based on the commodities produced. Chapter 15 is arranged alphabetically according to commodities.

The most fundamental division of commodities is into *metals, nonmetallics, mineral fuels,* and *structural materials.* The term 'nonmetallics' is customary in these classifications, although 'non-metalliferous' is preferable in other contexts (*see* Chapter 3). The chief nonmetallics produced in Canada are asbestos, potash, sulphur, salt, and gypsum. Structural materials comprise sand, gravel, clay, cement, and stone of various kinds. Nonmetallics and structural materials are commonly spoken of collectively as *industrial minerals*, the word 'rocks' sometimes being included but 'industrial minerals' is generally understood to include rocks used in industry. The mineral fuels are petroleum, natural gas and its byproducts, and coal.

Metals are commonly divided into *precious*, *noble*, and *base* metals. The term 'precious' is a legal one referring only to gold and silver because certain special laws cover them. Gold, silver, mercury, and metals of the platinum group are called 'noble metals' because they do not oxidize when heated in air or water. All metals other than noble ones are 'base' metals. Because iron ores and iron mines have uses, sizes, and grades that set them apart from those of other metals, base metals other than iron, such as copper, lead, and zinc, are commonly grouped as 'non-ferrous' metals; in some contexts this term may include noble metals.

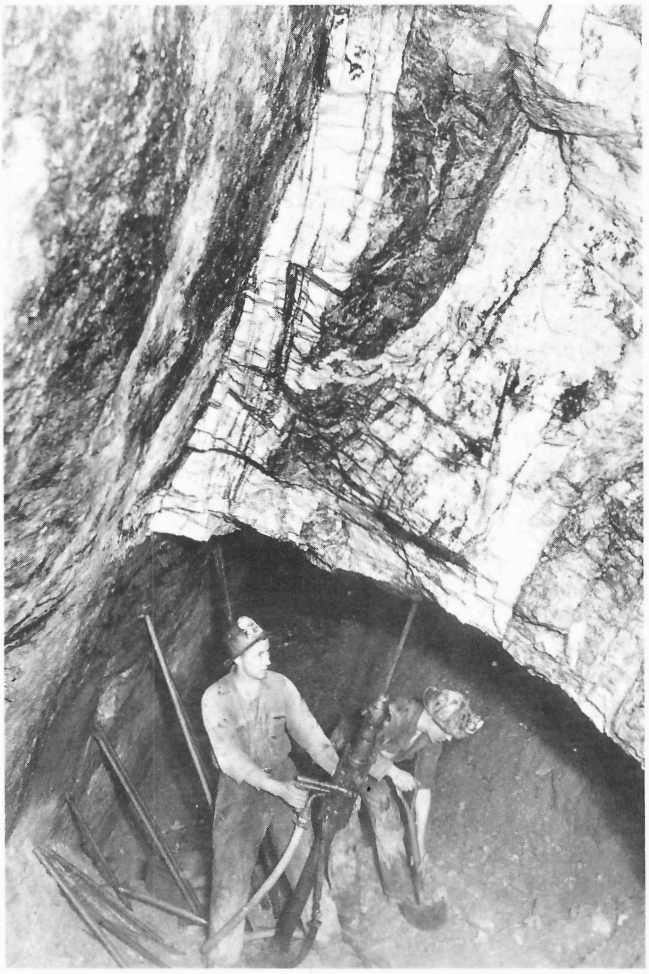
Many deposits yield more than one product. Those that are substantial factors in an operation are called *coproducts*, and minor ones whose sale does not substantially affect the operation are called *byproducts.* Deposits and mines are commonly classed according to the two or three main coproducts, as zinc–copper or gold–copper deposits, etc. Reference is generally to the values rather than the quantities. For example gold is much more valuable than copper, so a relatively small quantity of gold compared to that of copper would justify the description 'gold–copper', and 'copper–gold' would imply that more revenue was obtained or expected from sale of the copper than of the gold.

Shapes of Deposits

The shapes or forms of deposits are important considerations because they commonly provide the first indication of an occurrence or deposit seen by a prospector and may

influence the directions in which he works to reveal more of a discovery. Also, the shape of a deposit, the way it lies, and its regularity will certainly affect any appraising, testing, and perhaps mining that may be done (*see* Chapter 14).

Mineral deposits vary greatly in shapes, as in other characteristics, but are of two main shapes: (1) *tabular* bodies, and (2) irregularly shaped bodies to which no single descriptive name can be given. The word 'tabular' is used to describe bodies that are relatively long and wide (slab-like) in relation to their thickness. It is derived from the same source as 'table', but tabular deposits may lie vertically or on a slant, as well as horizontally. In addition to veins and vein-like deposits, tabular bodies include evenly mineralized dykes or sills and *stratiform* deposits which have the general appearance of strata and are commonly layered between strata. Stratiform deposits may be flat or tilted, or folded with the rocks above and below them. All tabular deposits are closely related to structural features, mainly fractures, faults, bedding-planes, and folds. Irregularly shaped bodies exist in a great variety of shapes and sizes, and are commonly without such obvious structural relations as are tabular deposits.



L. Frank 78607

Plate 30. A large banded quartz vein being mined for gold.

The simplest veins are single tabular bodies along fractures in rock. Some veins have regular walls and fairly equal thicknesses but others, having irregular walls, pinch and swell in size or may even be discontinuous. Some veins consist only of one mineral such as quartz or calcite, but most contain two or more minerals. Many are internally banded, as shown on Plate 30; the bands may consist only of different vein minerals, or some may contain bands of altered 'host' rock. Relatively short veins that appear to fill gashes in rock are called *gash veins* (*see* Pl. 35). Veins that taper in lenticular fashion are called *lenses*. Small, narrow veins are called *stringers* and *veinlets*.

Instead of occurring individually, many veins or stringers lie in groups, forming 'branching veins', 'compound veins', 'vein systems', and 'stringer systems'. A series of closely spaced, virtually parallel stringers forms a 'sheeted vein', and a network of stringers joining one another at various angles forms a *stockwork* (*see* Pls. 31 and 32). A series of small veins lying at right angles to two parallel fractures, like the rungs of a ladder, is called a 'ladder-work'.

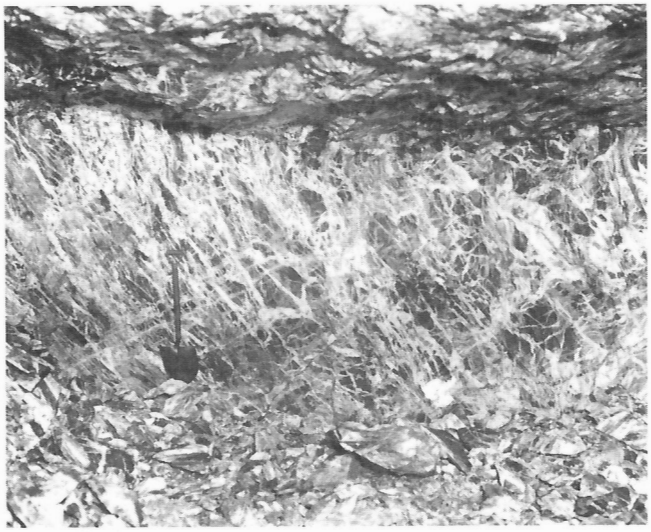
A fault that is marked by a zone of sheared rock may contain veins or be mineralized in other ways, forming *shear zone deposits*, some of which are very large. Deposits formed around fragments in breccias of fault or other origins are called *breccia fillings*. Cavities formed in limestone or other soluble rocks by the action of percolating surface water may later have minerals deposited in them to form *cavity fillings*.

Pipes (chimneys) are almost cylindrical or irregularly shaped bodies that are relatively long in one direction and short in the other two. They commonly are breccia-fillings in volcanic explosion openings or are formed at the intersection of two structural features, such as a particular stratum crossed by a fault or the intersection of two faults (*see* Fig. 6).



H. C. Gunning 81941

Plate 31. Stringers of quartz following parallel stringers in syenite.



C. H. Stockwell 81925

Plate 32. A stock-work of gold-bearing quartz stringers, following a network of fractures.

Consolidated and Unconsolidated Deposits

The unconsolidated or consolidated (hard-rock) nature of a deposit is a fundamental consideration for prospecting and for testing and working deposits. Some unconsolidated deposits are simple sediments, others are concentrated in various ways, explained later. Many unconsolidated metallic deposits are called *placers* (alluvial deposits) in contrast to consolidated metallic deposits that are called *lodes*. Early use of the term 'lode', which is derived from 'lead', was restricted to a vein or a special type of vein-system, but it has largely been accepted in Canada as meaning any kind of 'hard-rock' deposit. Some authorities, however, exclude stratiform and nonmetallic deposits.

Geological and Other Associations

Mineral occurrences and deposits consist of grains or crystals of one or more mineral types, which themselves are groupings of chemical elements. Elements and minerals have certain affinities that tend to cause them to occur together. Such associations are helpful in understanding and describing deposits, and are often useful in prospecting because, if a certain element or mineral has been shown to be present, another and perhaps more valuable one may be expected. Consideration of whether the valuable minerals are grouped in masses or are finely scattered is also necessary. Also important are the relationships of deposits to the host rock in which they occur, as various deposits are related in different structural ways to these rocks, and certain classes of deposits tend to occur in rocks of certain kinds and ages. The associations of elements, minerals, and rocks are large and complex subjects that are developed as far as possible here and in later parts of this book, and still further in many publications on individual areas and classes of deposits. The subjects are introduced in the following paragraphs, the discussions being based on actual observations unrelated to facts or theories regarding the origins of deposits.

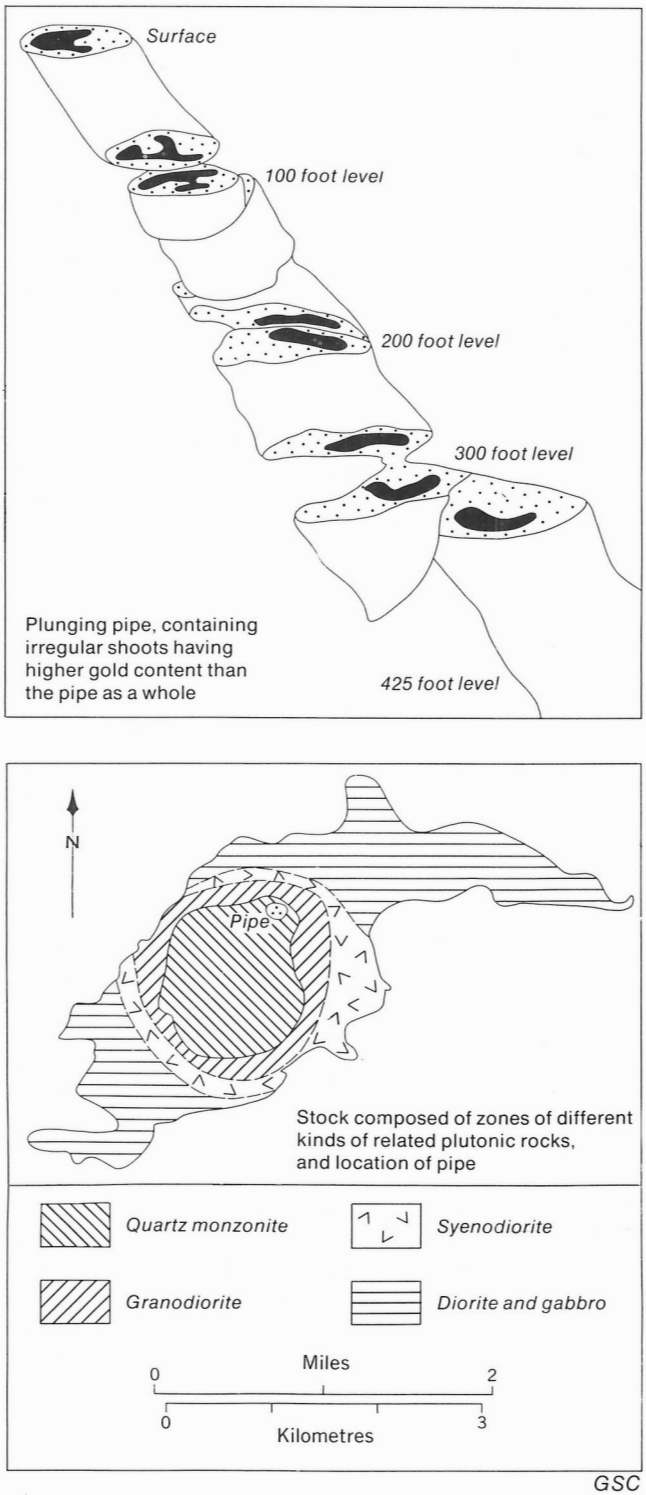


Figure 6. Cut-away side view of pipe-like mineral deposit, and plan of larger area showing location of pipe with respect to a stock composed of rocks of different compositions.

Elemental Associations

Many of the metals and non-metallic elements have fairly similar chemical and physical properties and are commonly associated in a single mineral or deposit or a group of de-

posits. Among the best known of such relationships are lead and zinc; copper and zinc; uranium, thorium, and radium; gold and silver; molybdenum and tungsten; nickel, platinum, and palladium; and titanium, vanadium, chromium, manganese, iron, cobalt, and nickel. Also, the common metals have strong affinities for oxygen and sulphur, and some metals have affinities for oxygen and carbon acting together. Selenium and tellurium are related to sulphur and combine with some metals instead of sulphur. These and other associations, as well as some of the reasons for them, are illustrated in a 'periodic' chart of the atoms, such as Appendix II.

Mineral Associations

The presently valuable parts of orebodies are called *ore* and the remainder is called *waste*. These terms are also being used increasingly in connection with deposits of industrial minerals. Although some ores consist entirely of valuable minerals, most are fine or fairly fine grained aggregates of valuable minerals, called *ore minerals*, and worthless minerals, called *gangue*, which must be separated from the ore minerals by concentrating or smelting. In some deposits or parts of them the gangue consists of altered rock instead of typical gangue minerals. Some authors restrict 'gangue' to worthless non-metalliferous minerals, whereas others, including the writer of this book, include minerals such as pyrite and pyrrhotite unless they are being recovered for production of iron or sulphur.

Commonly observed associations and manners of occurrence of ore and gangue minerals are important considerations in prospecting but generalizations on them should not be adopted too implicitly because valuable minerals can occur in less typical associations. These matters are discussed more fully in Chapters 9 and 15, as only a few of the principal points are mentioned here.

Gold does not readily combine chemically with other elements, but it does combine with tellurium to form the telluride groups of minerals. Gold generally occurs as disseminations or veinlets in quartz or as inclusions in pyrite, chalcopyrite, and to some extent in other sulphide minerals. When the particles of gold are large enough to be freed by grinding away of the gangue, the gold is said to be *free milling*. The particles of gold in sulphide minerals are generally of microscopic size, which makes necessary the roasting of the sulphide minerals to drive off the sulphur and free the gold before panning or smelting is done. Some silver is almost always alloyed naturally with gold. Silver also occurs commonly with sulphide minerals of lead and zinc, and fairly commonly as native silver.

The principal copper mineral is chalcopyrite, often associated with gold, with sulphide minerals of lead, zinc, and nickel, and with pyrrhotite. Pyrrhotite at some localities is associated with pentlandite, an important ore mineral of nickel. The platinum group of metals is commonly associated with nickel-bearing minerals.

Ore minerals occur in either *massive* or *disseminated* forms. Masses of one or more minerals range in size from about an inch to one hundred feet or more. In disseminations the ore minerals are scattered fairly evenly in gangue, which may consist of one or more gangue minerals or of altered rock; the sizes of grains of ore minerals range downward from those of grains of wheat to microscopically fine particles. Some deposits consist partly of massive minerals and partly of disseminations. Many consist partly of sections that are of ore grade, together with sections that are not. The valuable parts are then called *ore shoots*, which may lie at the boundaries or centre of a deposit, or at places where the deposit or its enclosing wall-rocks were fractured in a certain way, or where the wall-rocks have a certain chemical nature. The boundaries of ore shoots may be visible because of obvious mineral content, or they may be invisible and require outlining by careful sampling and assaying.

Rock Associations

Mineral deposits are divisible structurally into two fundamental classes called *concordant* and *transgressive*. Concordant deposits conform with layered host rock, or host rocks if they lie between rocks of two kinds. Most concordant deposits are stratiform but the term is a little more general than that. Transgressive deposits comprise all those that lie across the attitude of their host rocks, or which occur in fractures or other linear openings in a plutonic rock. Transgressive deposits include most veins, stringer systems, breccia fillings, and mineralized dykes, but would not include a vein or other deposit whose strike and dip is parallel with enclosing strata.

The rocks in which mineral deposits are found may be important because of their chemical or physical characteristics, class, or age. These are important considerations for individual districts or deposits, but most information on these subjects must be obtained from Chapter 15 or from more detailed reports on areas or mines, because few obvious country-wide or world-wide generalizations can yet be made. Fractures, and veins and other deposits filling them, do tend however to occur in the stronger, more 'competent' or more brittle rocks (*see* Pl. 35). Many deposits carrying gold, tungsten, tin, or molybdenum occur in rocks ranging from granite to diorite. Nickel, chromium, and platinum are commonly associated with gabbro and ultramafic rocks.

The ages of sedimentary, metamorphic, and igneous rocks in which deposits are found are important for individual districts but only a few broad generalizations can be made. Precambrian rocks are the chief Canadian source of metalliferous ores, but this is not surprising, because Precambrian time represents five-sixths or more of entire geological time and because Precambrian rocks are exposed, or covered only by clay, sand, or gravel, over half the country. Deposits of mineral fuels do not occur in Precambrian rocks. Metalliferous deposits have so far been found in only a few parts of the Platform Regions (*see* Chapter 5). Large expanses of Tertiary rocks in the interior of British Columbia are younger than almost all the metalliferous deposits of that province and so are not favourable for prospecting, apart from exceptional circumstances.

Attempts have been made to assign the deposition of particular metalliferous ores to distinct geological periods

or cycles of orogeny, called 'metallogenic epochs'. Undoubtedly there were times, during the Precambrian and later, when the deposition of sedimentary deposits, such as those of iron, was most marked and when orogenies and their associated plutonic rocks produced unusually large numbers of metalliferous deposits in general, as mentioned in Chapter 5; however, efforts to link specific metals to one or two metallogenic epochs rather than others have in general not been convincing.

Suggestions for Additional Reading

Bateman, A.M.
1951: The formation of mineral deposits; New York, Wiley.
A medium size book for laymen and beginning students.

The following are standard textbooks, any of which would amplify the book mentioned above.

Bateman, A.M.
1950: Economic mineral deposits; 2nd ed., New York, Wiley.
Lamey, C.A.
1961: Metallic and industrial mineral deposits; Toronto, McGraw-Hill.
Lindgren, W.
1933: Mineral deposits; 4th ed., Toronto, McGraw-Hill.
Park, C.F. and MacDairmid, R.A.
1964: Ore deposits; San Francisco and London, W.H. Freeman and Co.
Routhier, P.
1963: Les gisements métallifères; 2 vols., Paris, Masson.

ORIGINS OF DEPOSITS

Mineral deposits were formed in many ways and at greatly different depths beneath the surface then existing. The way in which some types of deposits originated is clear, but the origins of many other types is only partly understood. The origins of some can be explained by two or more conflicting theories. The main causes of these uncertainties are due to the incompleteness of knowledge of conditions below the observable part of the crust. Although some classes of mineral deposits can be observed in the process of formation at the surface, most were obviously deposited or altered from their first-formed state at depths of hundreds or thousands of feet, or even miles, beneath the surface then existing. They have since been exposed by erosion or at least brought within the ranges of drilling and mining. Although much has been learned indirectly about conditions in the depths of the crust, this knowledge is not yet sufficient to establish all the genetic features of many deposits. A second difficulty is that some deposits grade from one type to another or have been formed partly by one process and partly by another. A third difficulty is that the terminology is not fully standardized; the principal terms and variations in usage are explained here and in the glossary.

Genetic considerations are of great practical importance in the selection of regions and localities for prospecting, and commonly in the appraisal of prospects and mines, in testing prospects, and in searching for additional ore at mines. Although much has been learned about the origins of deposits, a great deal more research is required. Meanwhile, many practical problems can be handled by using generalizations which lack full knowledge of the mode of origin of a particular class of deposit. Conventional prospectors can rely largely on such generalizations, without studying genetic principles extensively, but they should understand the main facts and theories. As regards more advanced prospecting, the growing need for additional ores which are difficult to recognize by conventional prospecting, and for orebodies covered by overburden or barren rock, must be filled mainly by deposits found by advanced prospecting programs, for which genetic knowledge and theories will be vital factors.

The main facts and accepted observations, and the more speculative theories, on the origins of deposits of different kinds are outlined in the following sections and discussed further in the later sections on individual types of deposits.

Main Genetic Facts and Observations

The main facts and observations regarding the origins of certain classes of mineral deposits may be grouped as follows: (1) material now being formed at the surface, or consolidated deposits that obviously were formed from such material deposited on a geologically ancient surface; (2) positional relations to bodies of plutonic rocks; (3) obvious genetic relations of some deposits to bodies of igneous rocks; (4) numerous analyses of rocks and the waters of oceans, lakes, springs, etc., which permit fairly reliable averages of the amounts of various elements in the different kinds of crustal rocks and in the waters on and near the earth's surface; (5) laboratory tests and experiments on the melting points and ages of rocks and minerals, on the formation of synthetic minerals at various temperatures and pressures, on samples from the bottoms of seas, lakes, and bays, experiments with artificial seawater, and so on; and (6) evidence that certain deposits filled open spaces in rocks and that certain others were formed by the 'replacement' of previously existing minerals or rock.

Observable Deposition. The formation of a few types of deposits can be observed at or near the earth's surface. Minerals deposited around the outlets of hot or cold springs are a common example. Deposition of sand, gravel, clay, marl, and peat can be observed, as can the results of evaporation called *evaporites*, such as salt and 'alkali'. The action of waves in concentrating *placers* along beaches can be seen. Construction and study of model streams has proved the origin of *stream placers*. Some ancient geological formations contain sedimentary deposits that were obviously consolidated from normal sediments or placer concentrations.

Weathering causes oxidation of the upper parts of many metalliferous deposits, thus forming secondary minerals that can be seen in place. Weathering also alters some rocks to form residual deposits of iron, aluminum, and other minerals which remain in place; some of these are called *laterites*. Products of weathering that are transported and sorted by streams, waves, or winds cause the accumula-

tions of gold or other heavy or hard minerals that form placers.

Comparisons between some marine sediments and some consolidated iron deposits leave no doubt that the latter are marine sediments consolidated into sedimentary rock. Some evidence suggests that seawater is enriched in iron near and at the time of the extrusion of submarine lavas, but this does not alter the sedimentary nature of the deposits. Some manganese deposits are also clearly sedimentary. The action of bacteria is known to precipitate copper in water, but the origin of certain stratiform deposits in shale and other rocks carrying copper and other metals, which have generally been regarded as classical examples of sedimentary deposits, has been challenged recently by alternative theories.

Analytical Evidence. Geological evidence for all known mineral deposits shows that they were formed after the original crust of the earth had formed. No sign of the original crust has been found in the Canadian Shield, all deposits in it and in younger formations being in typical sedimentary or volcanic rocks, or rocks altered from them, or in plutons in them. It is, therefore, accepted that all mineral deposits are concentrated in some way from rocks of kinds that can now be observed, or from material added from the mantle, or that they result, to a limited extent, from the fall of meteorites and dust from outer space.

Numerous analyses of samples of various kinds of rocks, including those of volcanic origin which denote the compositions of certain magmas, indicate the relative amounts of the elements present. Several tables for such information, although differing in details, are essentially similar. Calculations made from such data and from the average contents of typical ores indicate the approximate concentrations of metals involved in the formation of metallic ore deposits. These are listed for some of the principal metals in the accompanying table.

Concentration of Metals in Common Ores

Metal	% in Average Igneous Rocks	% in Average Ores	Number of Times Concentration
Molybdenum	0.00015	0.1–0.4	667–2,667
Uranium	0.00027	0.1–0.3	370–1,111
Lead	0.00125	2.5–10	2,000–8,000
Zinc	0.007	4.5–10	643–1,429
Nickel	0.0075	0.8–3.5	107–467
Copper	0.0055	0.5–3.0	91–545
Iron	5.63	20[1]–60	4–11

[1] Including modern concentratable ores.

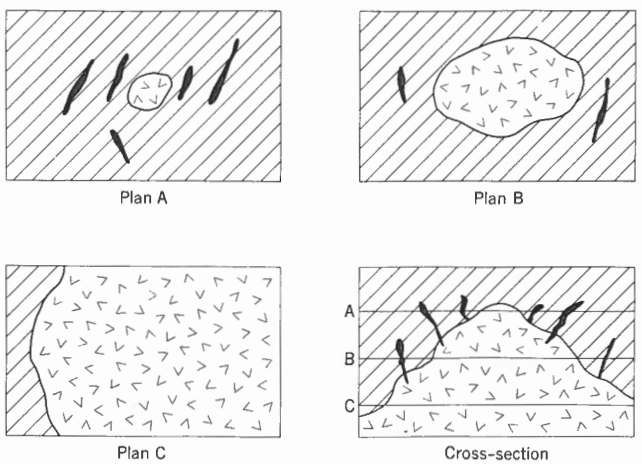
Deposition by Igneous Rocks. Some deposition by volcanic activity can actually be observed taking place or immediately after it has occurred, and certain deposits in plutonic rocks were so obviously formed during the formation of the rocks that their origin is not questioned.

Gases given off by active volcanoes and minerals deposited near small vents (fumaroles) on volcanoes have been studied carefully. Large quantities of water vapour, hydrochloric acid, hydrofluoric acid, and hydrogen sulphide are emitted. Abundant magnetite and sulphur are deposited near some fumaroles and smaller amounts of zinc, copper, and lead sulphides have been observed. These surface deposits are of little or no commercial value but they are highly significant as possible explanations for other deposits.

Certain deposits in mafic and ultramafic rocks have so evidently been concentrated by settling from the magma from which the main rock crystallized that they are unquestionably classed as *magmatic segregations.* Other related deposits show evidence of having been injected into rocks during magmatic processes. Some mafic and ultramafic rocks are believed to represent magma from the mantle. Evidence indicates that during the magmatic processes iron and titanium may be deposited in mafic or siliceous fractions, but that chromium, nickel, and platinum are concentrated in the more mafic parts.

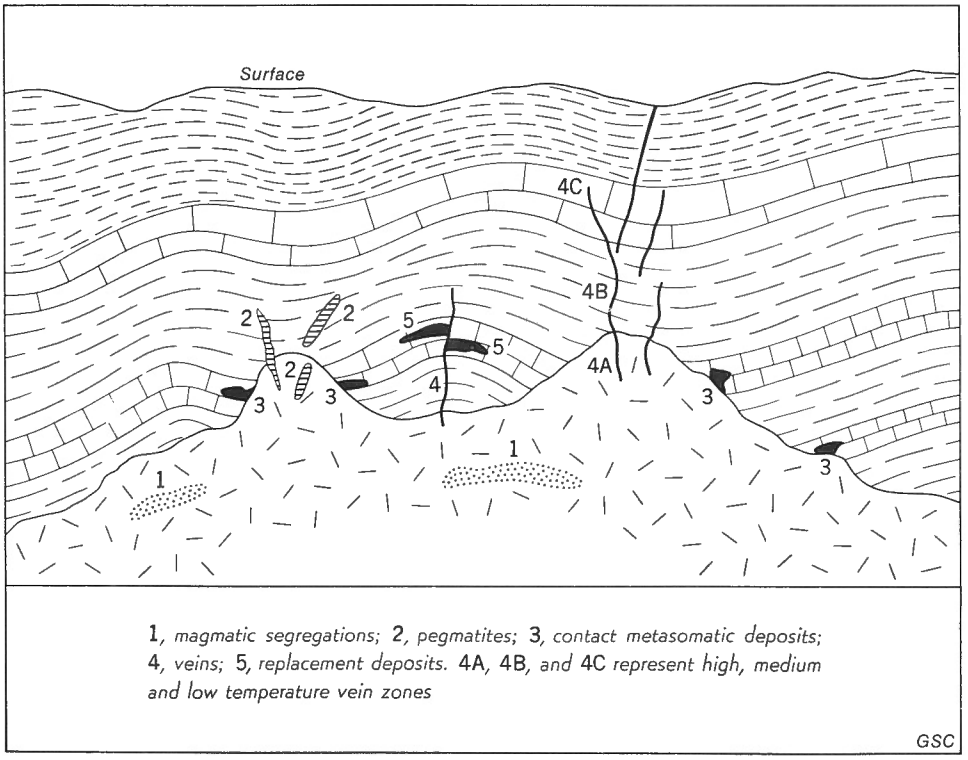
Many pegmatite deposits occurring in or near plutonic rocks seem obviously to have been segregated during the formation of these rocks. Pegmatites are most commonly associated with siliceous rocks such as granite, but some mafic examples are found also. The origins of other pegmatitic deposits in plutonic and other rocks are more complex, as mentioned later in this chapter. Students may be confused by the term pegmatite because in one sense it is the name of a rock and in another sense the name of a kind of mineral deposit; in the latter case it is a deposit of pegmatitic rock of interest for one or more of its essential or accessory constituents.

Spatial Relations to Igneous Rocks. Many deposits, of several forms and mineral types, occur in the upper parts of stocks and batholiths or in the invaded rocks above and beside them (*see* Figs. 7 and 8). They are particularly well seen in mountainous regions, such as the interior of British Columbia, where deep valleys provide three-dimensional exposures. At one mine in Mexico the writer has seen



The batholith is shown by angle pattern, the intruded rocks by oblique lines, and mineral deposits by solid black. Three stages of erosion are illustrated by plans A, B, *and* C, *and also by the corresponding levels* AA, BB, *and* CC *in the cross-section. At stage* C *all deposits have been destroyed by erosion.*

Figure 7. Spatial relations of mineral deposits to a batholith at different levels of erosion.



1, *magmatic segregations;* 2, *pegmatites;* 3, *contact metasomatic deposits;* 4, *veins;* 5, *replacement deposits.* 4A, 4B, *and* 4C *represent high, medium and low temperature vein zones*

Figure 8
Spatial and possible genetic relations of deposits of several kinds to a large pluton.

plutonic rock and a metasomatic deposit in the bottom of a deep canyon. Above this deposit is a 'chimney' in limestone containing silver, galena, and sphalerite, with oxidized minerals in its upper parts.

Many examples of spatial relationships of deposits to plutons have also been observed in the Canadian Shield, where the flatter topography generally makes it necessary to compare the surface evidence of one area with that of others having relatively different levels of erosion. The relations can also be seen in some mines where deposits in sedimentary, volcanic, or metamorphic rocks can be traced downward into plutonic rocks.

So much evidence of spatial relations between some deposits and plutonic rocks has been collected from various countries that the existence of some kind of association is unquestioned. This generalization does not prove that the elements forming the deposits necessarily were derived from magmas that formed the plutons, nor does it indicate that all deposits of these kinds were formed in the same way. In areas where spatial relations of these kinds have been reported or observed, the generalization has commonly been applied successfully in a common-sense way to the selecting of places for further prospecting and to the solution of prospecting and mining problems, regardless of whether all details of the origin of the deposits concerned were understood.

Many concordant and transgressive deposits occur in thick successions of volcanic, sedimentary, or metamorphic strata, without observable spatial relationships to plutons. The number of examples, and geochemical data on the deposits and their host rocks, is increasing as more deposits and mining areas are studied in detail.

Experiments. Research has provided much information on the temperatures, pressures, and other conditions at which various minerals form or are converted to other minerals, and more work of this kind is being done. These results are most indicative for deposits formed at the surface or close to it. The results are less conclusive for deposits formed at greater depths because of uncertainties as to the exact amount of erosion that revealed the deposits and the exact conditions prevailing at various depths.

Experiments have shown that copper can be deposited by the action of bacteria on artificial seawater, and bacteria found in some secondary deposits are believed to have caused deposition of certain minerals.

Fillings and Replacements. Some minerals were obviously deposited in original openings such as vesicles in lava and uncemented spaces in sandstone and conglomerate. Others were deposited in cavities resulting from the circulation of water in soluble rock such as limestone. Many veins occupy fractures that were either open at the time the veins were deposited, or were closed but under pressure that could be reduced sufficiently to permit the pressure of vein-forming fluid or growing crystals to force the rock apart. (A fluid may be a liquid or a gas, or a combination of these.) Two simple examples of fissure veins are illustrated on Figure 9. If a fissure crossing a stratum or other recognizable feature, as shown on drawing A, is opened or forced apart, the intersections of the boundaries of the stratum will be offset as shown on drawing B. Relationships of this kind, often seen in outcrops and mine workings, are proof that a deposit filled an open space or a potentially 'dilatable' space (i.e., a fissure whose walls could be forced apart). Diagram C illustrates a replacement-vein that does not displace the

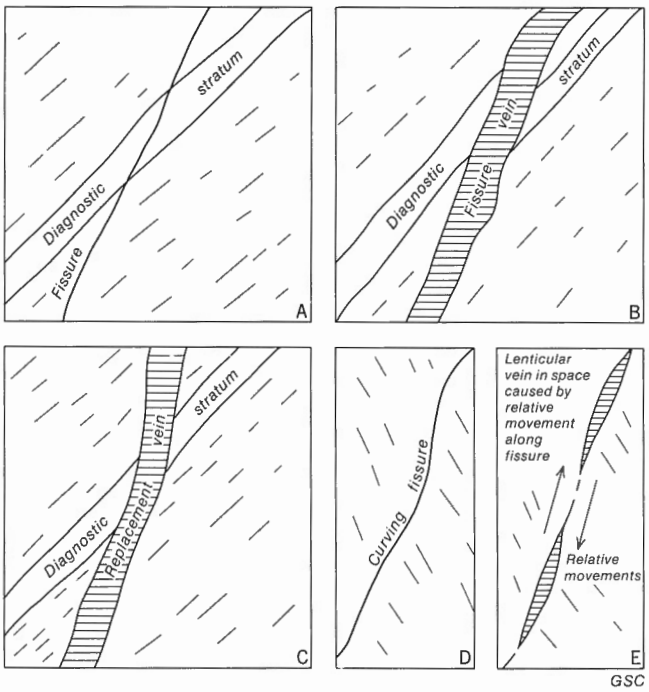


Figure 9. Distinction between fissure vein (A and B), replacement vein (C), and a cause of lenticular openings (D and E). The fissure (A) has opened accommodates the vein (B) but not vein (C).

strata. Drawings D and E illustrate the manner in which movement along a curving fissure causes lenticular openings or zones of reduced pressure wherein minerals may be deposited by circulating fluid. The origins of some other fracture patterns are as acceptable as these, but need not be described here.

Other kinds of deposits have clearly been formed by replacement. This is a process by which minerals existing in a rock or mineral deposit were dissolved by a fluid which deposited another mineral in its place. These changes are caused by chemical conditions brought about by the presence of the invading fluid, the substituted mineral or minerals being more stable in the changed circumstances. Some evidences of replacement, such as 'ghost' remnants of the original mineral or rock, seen in rock exposures or 'hand' specimens, are accepted without doubt by geologists. Other evidence can be seen with a microscope, and laboratory experiments clarify some of the processes. For many deposits, however, the evidence is not clear and origin by replacement is regarded only as a probable or possible origin. Some deposits described as replacements in early reports are now considered to have been formed mainly by another process accompanied by minor replacement.

Wall-rock Alteration. Many deposits are flanked, surrounded, or partly surrounded by zones of altered rock a few inches to many feet wide. These zones may or may not contain minerals that also occur in different amounts in the deposit itself. The colour and mineral content of the zones commonly grade outward, gradually blending into unaltered rock. The alteration is commonly caused by the presence of silica, white mica, carbonate, clay minerals, chlorite, or hematite, or combinations of these, which produce grey, green, or reddish brown colours. Dark coloured rocks are commonly bleached to lighter grey or green colours.

Main Genetic Theories

Late in the 18th century Europeans whose observations formed the beginning of modern geology began a controversy regarding the origin of rocks and their associated mineral deposits. One group argued that all rocks, including granite, were deposited in an original ocean enveloping the earth, and that veins were sediments filling cracks in the floor of this ocean. The other group maintained that igneous rocks and mineral deposits crystallized from magmas injected into crustal rocks from molten material underlying the crust. These two concepts hold much of the essence of current thinking regarding the many types of deposits whose origins are not obvious. The advocates of sedimentary origin for all deposits were correct so far as simple sedimentary deposits in their original or hardened states are concerned. Modifications of the sedimentary concept form the basis of 'lateral secretion' and other theories to be mentioned later. The advocates of igneous origin were correct at least so far as magmatitic segregations, including some pegmatites, are concerned. They may also have been correct regarding the formation of many veins and other open-space fillings, and replacements. Their ideas of the source of magmas and the manner of crystallization of magmas, however, are considered by most modern geologists to have been overly simple.

The discussion of the origin of plutonic rocks in Chapter 2 mentions that many plutons show evidence of having been transformed from sedimentary rocks by processes, grouped under the term 'granitization', which are regarded as deep-seated phases of regional metamorphism, probably accompanied by some mobilization and transport of elements in the rocks so affected. Some geologists believe that these phenomena are parts of a cycle which, if completed, would result in typical metamorphic rocks at moderate depths below the existing surface, or in areas affected by moderate tectonic stress. They believe that granitization takes place below the zone of typical metamorphism or in areas of greater stress, and that at still greater depths crustal rocks may be melted to form magma. All these effects are thought to be related to the gradual accumulation of sedimentary and volcanic strata in geosynclines, and their upheaval to form mountains. The folding or crushing would cause fracturing of rocks and create zones of lowered pressure in which heated rocks could liquefy to form magma, and fluids from such a magma might tend to fill fractures or to replace rock. According to these concepts magmas are not injections from the mantle. Perhaps, however, some magmas are formed in one of these ways and some in the other, or perhaps magmas that result partly from the recycling process have material added to them by diffusions or injections from the mantle. Some modern theories hold that some elements may be transformed to others in the mantle by such processes as radioactive decay, that heat is generated by such processes,

and that convection brings material toward the crust, where it forms magmas from which ores are wholly or partly derived.

Toward the close of the 19th century the origins of simple sedimentary deposits and magmatic segregations were well established, and replacement processes were beginning to be understood. Early in the 20th century a fundamental distinction between *syngenetic* deposits formed at the same time as their host rocks, and *epigenetic* deposits formed later than their host rocks, was well established. These terms are still useful but cannot be applied rigidly to all cases. For example, a deposit may show much evidence of being essentially syngenetic in origin, but may be considered to have been formed slightly after the rock enclosing it, or to have minor epigenetic phases. Spatial relationships between plutons and many deposits became increasingly apparent, leading to the explanation of *metasomatic* deposits (*see* p. 53) being related to igneous processes, and to the *hydrothermal* theory for the origin of veins, other open-space fillings, and replacements. The hydrothermal theory accounted for the deposition of these by hot ascending fluids containing metals and other elements emitted from a magma during the last stage of its cooling and solidification. Whether the fluids themselves were expelled from the magma, or were groundwater that had circulated deep enough to become heated and charged with elements from the magma, or were a mixture from both sources, remained in doubt. Variations of the hydrothermal theory explained so many spatial relationships to plutons and observations of zoning — as well as observations that many gold deposits seem to be related to granitic rocks, whereas copper and several other metals seem related to more mafic rocks — that it became the dominant explanation, particularly in North America. In the first quarter of the 20th century the hydrothermal theory was so popular that many geologists believed that veins, replacements, and stratiform deposits found in areas where no body of plutonic rock were exposed were evidence of a deeper seated body not yet revealed by erosion.

Despite the attractions of the hydrothermal theory, it was challenged by the 'lateral secretion' and related theories to explain the presence of sedimentary deposits that appeared to have undergone changes after being buried in the crust, and the presence of replacement deposits in limestone and other rocks in districts where no spatial relationships to younger plutonic bodies were observed. According to these theories, metals were dissolved from pre-existing mineral deposits or from small amounts of metals in normal rocks by groundwater circulating laterally, and were deposited (secreted) where chemical conditions dictated. Such water might have been heated to some extent by passing through rocks whose temperature was greater than that of surface rocks, because of the normal increase in temperature with depth, but no heating by proximity to cooling magma was thought to have occurred. The popularity of the hydrothermal explanations caused lateral secretion theories to be largely abandoned except for the alteration of near-surface parts of deposits. In recent years these theories have been revived and modified in what is sometimes called the 'source-bed concept', according to which, the sedimentary, volcanic, or metamorphic rocks in some mining districts have been shown by chemical analyses to contain enough metals, sulphur, silica, etc., to have been the source of younger deposits occurring in them. Some of these deposits may have been concentrated by groundwater, and others may have been 'sweated out' of the rocks by metamorphism or diffusion. The term 'lithogene' has been proposed for deposits apparently formed in one of these ways.

Although many non-metalliferous deposits and some metalliferous ones, most notably some iron-formations, are regarded as unquestionably sedimentary, the origins of other stratiform deposits are problematical. Some show evidence of remobilization and replacement, which leads to theories that accumulations that were originally sedimentary were modified by some kind of lateral secretion. Other deposits, which appear to contain more metal than would probably be deposited by normal seawater, are thought to have resulted from seawater enriched by hydrothermal fluids which escaped from springs, or by material given off from submarine flows of lava. Still other deposits are believed to have been deposited directly by exhalation from lavas, perhaps trapped by flows or sediments covering them. The realization that many deposits, including many of the principal ones of the Canadian Shield, occur in belts of sedimentary or volcanic rocks or their combinations, without being obviously derived from magmas, has recently caused coining of the expression 'strata-bound deposits'. These include stratiform, vein-type, replacement, or other kinds of deposits, as long as they occur entirely within a 'pile' of strata and are not controlled by later structures. 'Strata bound' does not literally indicate that the elements of the deposit were concentrated in some way from the pile, but most who use the term seem to imply this.

Better clarification and evaluation of the theories outlined above are needed for immediate practical applications and as more general basic information. Investigators naturally tend to take sides and to argue that one or another process is correct, and also tend to be influenced by evidence available in the regions where they have worked. If the complexity and time of geological processes in general is considered, the likelihood that some doubtful deposits were formed in one way and some in another, or by combinations of processes, seems reasonable. Perhaps some of the conflicting opinions relate only to the position of a deposit, at the time of its formation, in relation to a mountain-building or granitization cycle. Clearer understanding of these problems seems to be developing now as results of geochemical, microscopic, and isotopic studies, combined with greater awareness of the associations of many deposits to geosynclines, orogenies, and their tectonic effects. International focusing of studies of mafic and ultramafic rocks, now being carried out, are expected to clarify the relation of such rocks and their associated mineral deposits to the mantle. The origin of more siliceous plutonic rocks and their associated deposits seems likely to remain controversial for a longer time.

Metamorphism of Deposits. The possibility that some deposits are formed or re-formed by intense metamorphism that resulted in granitization or a related process has already been mentioned. In addition, certain deposits have undergone metamorphism of lower rank, along with their host rocks, without destroying the essential character of the deposits. Such metamorphism may cause changes in crystallization and texture of minerals in a deposit, or may result in some mobilization and recombination of elements to produce new minerals. Important examples of this kind are iron ores in Quebec, Labrador, and Ontario where metamorphism has a definite economic bearing on crushing and grinding techniques.

Hypogene and Supergene Deposits. For some purposes it is convenient to refer to deposits as being either *hypogene* (primary) or *supergene* (secondary). A primary deposit is generally thought of as one that has undergone no change since its deposition, and a secondary deposit as one that has been derived from a primary deposit by the chemical action of seeping surface waters that did not carry the material far from its primary source. This is often a useful distinction, but the use of the words requires qualification. Modern theories of the formation of igneous rocks and mineral deposits indicate that metallic and other elements may have been re-cycled several times within the earth's crust. Deposits containing such elements would still be primary in the sense implied here. Also, some primary deposits have been metamorphosed and have thus undergone change since deposition, but are not secondary in the sense used here. For these reasons the terms 'hypogene' and 'supergene' are more accurate. 'Hypogene' was first used as a group term for plutonic and metamorphic rocks and later for geological processes originating within the earth. It was applied to mineral deposits believed to have been deposited by upward-moving solutions, but in view of the more general geological usage it seems appropriate to apply it to any deposits that were formed at depth and which are not supergene.

Genetic Classifications. The classifications discussed earlier in this chapter were descriptive and non-theoretical. Classifications based on the origin of the deposits concerned are more suitable for some purposes, particularly for selecting places to prospect for deposits of certain origins, and for evaluating deposits and solving certain mining problems. The preparation and use of genetic classifications are hampered because the origins of so many classes of deposits are not yet understood fully, because the evidence available for many individual deposits permits them to be placed in more than one category in a scheme of classification, and because the greatest usefulness of a classification may be at an early stage in the discovery or testing of a deposit, when least evidence is available. Genetic classifications are useful, however, for prospecting, for descriptions of deposits, and for indicating subjects for further research. Various schemes have been proposed, most of which are fairly complex and more detailed than the accompanying simplified table.

A SHORT GENETIC CLASSIFICATION OF MINERAL DEPOSITS

1. *Deposits formed far below the surface (hypogene deposits)*
   - A. Deposits crystallized directly from magma
     - i. Typical magmatic segregations (*syn.*)*
     - ii. Late-stage magmatic segregations (including some pegmatites) (*syn.*)
   - B. Deposits formed by metamorphism, circulating fluids, or diffusion
     - i. Metasomatic deposits (*epi*) †
     - ii. Deposits generally formed at lower temperatures and pressures
       - a. Open-space fillings (*epi.*)
       - b. Replacements (*epi.*)
2. *Deposits formed at the surface (other than supergene deposits)*
   - A. Sedimentary and related deposits
     - i. Normal sediments (*syn.*)
     - ii. Evaporites (*syn.*)
     - iii. Placers (*syn.*)
   - B. Other deposits
     - i. Laterites (*epi.*)
     - ii. Other untransported residual deposits (*epi.*)
     - iii. Volcanic deposits (*syn.*)
     - iv. Spring deposits (*epi.*)
3. *Supergene deposits*

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* Deposits essentially or commonly of syngenetic origin.
† Deposits essentially or commonly of epigenetic origin.

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MAIN CLASSES OF DEPOSITS

The following additional information on various classes of deposits is mainly from Canadian examples. The genetic classification outlined in the last section is followed so far as possible. Several leading Canadian types do not conform completely with it, which illustrates the problems of genesis and the imperfections of genetic classifications. Some of the examples mentioned briefly here are described more fully in Chapter 15, which also contains other examples.

Magmatic Segregations

Certain deposits found in batholiths, stocks, and sills (*see* Fig. 8) are concentrations of accessory minerals of the plutonic rock concerned, such as magnetite and chromite. Some such concentrations are formed at the time of crystallization of the main body of rock, apparently by the settling of crystals of ore minerals early in the history of the magma. Such deposits are doubtless syngenetic. Concentrations from residual magma during the closing stages of the formation of a plutonic body, and which are deposited in it, form late-stage magmatic deposits that are essentially syngenetic. Other deposits, showing evidence of replacement or veining, are regarded as transitional between syngenetic and epigenetic origins.

Many magmatic segregations are tabular stratiform deposits, flat lying or gently folded. Others are irregular in shape. The ore minerals are massive in some deposits and disseminated in others.

Magmatic segregations in granite and related rocks contain magnetite, titaniferous magnetite, ilmenite, hematite, cassiterite, zircon, or monazite. Magnetite, ilmenite, or hematite have been found in segregations in rocks of intermediate composition. Segregations in mafic rocks carry chromite, ilmenite, magnetite, or platinum. Canadian examples of these types are iron–titanium concentrations in anorthosite and gabbro in Quebec and Ontario; concentrations of chromite in gabbro in Manitoba; serpentinized ultramafic rocks in Quebec; the Muskox ultramafic intrusion in the Northwest Territories, which contains concentrations of chromite, pyrrhotite, and chalcopyrite and carries nickel and platinum; and nickel–sulphide minerals at the base of gabbro sills in the Thunder Bay and Rankin Inlet areas. The nickel–copper ores of the Sudbury area were at first regarded as classic examples of magmatic segregations from mafic magma, but later studies indicated more complex origin, as mentioned further in Chapter 15.

Carbonatites and Related Deposits

The name 'carbonatite' was typically applied to an unusual group of roughly circular deposits containing calcite and other minerals, associated with alkalic rocks such as nepheline syenite. They commonly contain different kinds of alkalic and carbonate rocks and fenites arranged concentrically. Some deposits appear to be volcanic necks and some to be related to circular collapse or pressure structures. Some deposits lacking any suggestion of circular structures contain rocks similar to those of typical carbonatites. Although carbonatites and related deposits have been studied intensively their origin is not fully understood. They may be magmatic deposits, in which case the carbonate compounds appear most probably to have been derived from the digestion by the magma of invaded limestone or other carbonate rock. On the other hand, they may be of metasomatic or hydrothermal origin.

Carbonatites and related deposits have attracted attention because many of them contain niobium and because small amounts of uranium have been found in some. Several

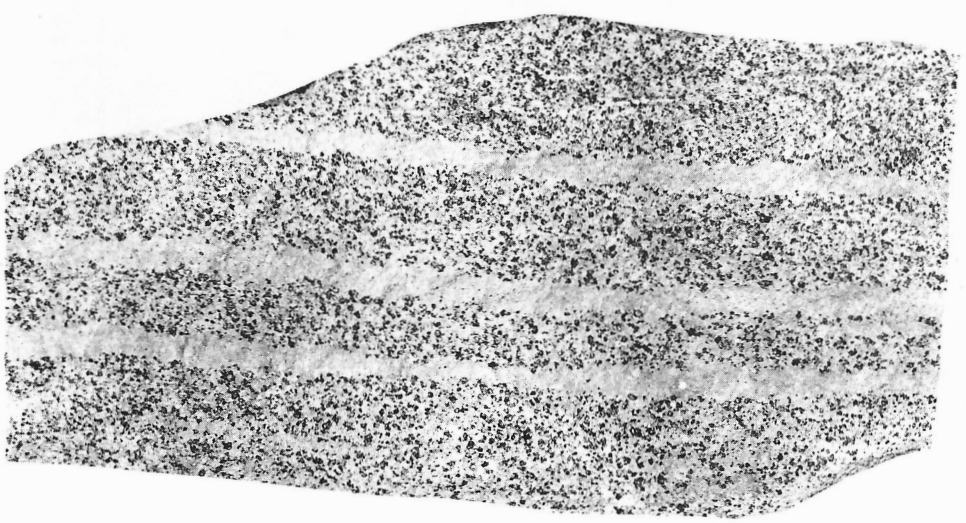

Plate 33
Specimen from a probable magmatic segregation deposit. Tabular stratiform bands containing chromite (black) in dunite, Eastern Townships, Quebec.

C. H. Stockwell 92168

Canadian examples contain pyrochlore and other minerals. One complex near Oka, Quebec, appears to be related to the Monteregian intrusions. Several have been found in the Canadian Shield in Ontario, and some are known in British Columbia. The circular arrangement of many deposits has caused investigation of several circular features seen on maps or air photographs. Some carbonatite deposits were discovered in this way but the other features were found to be caused by doming or other structures in which no carbonatite-like rocks or minerals could be recognized.

Pegmatites

Pegmatites, which were mentioned briefly in Chapter 3 because they are a type of rock, are discussed more fully here because they form one of the commonest classes of mineral deposits. Some pegmatites are evidently late-stage magmatic segregations, and others appear to have resulted from metamorphism or related processes that caused rearrangement and perhaps migration of some of the elements in previously existing rocks.

During the crystallization of many stocks and batholiths, elements and compounds such as water, fluorine, and carbon dioxide seem to have been concentrated in the still uncrystallized part, along with some of the ordinary rock-forming material and, in some instances, with metals and rare elements. After the main intrusive body was crystallized and fractures had formed, some of the still uncrystallized material appears to have been injected to form pegmatites in the plutonic body or in the invaded rock, or both. Some pegmatites replace parts of the plutonic or invaded rocks instead of filling open fractures. Some pegmatites are so intimately associated with plutonic rocks as to be regarded as syngenetic or nearly so; others are epigenetic deposits formed at high temperatures and pressures. Water, fluorine, and some other constituents appear to have had the effect of facilitating the coarse-grained crystallization so characteristic of typical pegmatites, some of which contain crystals several feet in size. Differences between porphyry and pegmatite are that the former contains scattered large crystals in a relatively fine-grained matrix, whereas most pegmatites consist entirely or mainly of coarse material, with only minor, if any, fine-grained patches. Also, the larger mineral units in porphyry always have distinct crystal outlines whereas those in pegmatites may have crystalline or irregular outlines.

Pegmatites are most commonly associated with granite, and such pegmatites are composed mainly of feldspar and quartz, together with lesser amounts of accessory minerals like mica, apatite, zircon, etc., all characteristic of the related granite. These pegmatites are properly called 'granite pegmatite'. Other, less common kinds such as 'syenite pegmatite', 'diorite pegmatite', etc., have the characteristics of the rocks with which they are associated; for example, syenite pegmatites do not have appreciable amounts of quartz, and diorite pegmatites contain the feldspars and the ferro-magnesian minerals typical of diorite. Some examples that are too fine-grained to be true pegmatites are classed as pegmatitic granite or pegmatitic syenite in some publications, but these terms may also refer to granite or syenite containing minor masses of true pegmatite.

Bodies of pegmatite are of many shapes and sizes, ranging from short bodies an inch or more wide to masses hundreds of feet or more in size, but most are fairly small. Many are properly called dykes, although few of these are as regular in form as the dykes composed of other kinds of rocks. They generally taper to form small or large lenses. Other bodies occur as sills and as irregularly outlined masses. Still others form narrow, virtually parallel sheets interspersed between layers of schist or gneiss, forming migmatite and *lit-par-lit* gneiss. 'Simple' pegmatites contain few mineral species, generally feldspar and quartz with a few accessory minerals such as mica, and they are unzoned. 'Complex' pegmatites contain a variety of minerals and are commonly composed of zones differing in sizes of crystals or in mineral content, or both. Many pegmatites have clearly defined walls, but others grade into the wall-rock as though the pegmatitic material had reacted with the wall-rock, or replaced it. Bodies of pegmatite commonly occur in groups, so that if one is found others are probably present in the same general locality. Pegmatites generally occur in plutonic or metamorphic rocks and are exposed



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Plate 34. A mass of pegmatite (white) containing crystals of phlogopite mica (black).

in regions that have been deeply eroded. Pegmatites are commonly present in clusters or 'swarms'.

Pegmatites are common in many parts of Canada but relatively few contain deposits of commercial value. Some deposits are of value because their coarse crystals permit them to be a source of common non-metalliferous minerals like feldspar, quartz, and mica, and some because they contain payable amounts of rarer minerals yielding lithium, beryllium, niobium, tantalum, molybdenum, tin, and other elements. These minerals are only minor constituents of most pegmatites, if they occur at all, and only exceptional occurrences contain enough of them to make mining profitable. Minerals containing uranium or thorium are found in many pegmatites, but rarely in commercial quantities. Gold and sulphide minerals like pyrite and pyrrhotite are found sparingly in some pegmatites, but pegmatites are not important sources of such minerals.

Most pegmatite deposits are relatively small, and even if they are mined for one or more valuable constituents this is usually done on a small scale. They are generally mined from surface pits, with portable equipment that can be moved to another occurrence when one body has been exhausted. Their main importance is as possible sources of metals, for example, beryllium and lithium, which are not likely to be found in larger and more uniform deposits of other types. Also, some unusual pegmatitic deposits have been mined for uranium. When searching for pegmatites containing such metals prospectors should remember that occasionally it is relatively easy to find a pegmatite with a mass or crystal of a mineral containing the metal sought, but that deposits containing commercial quantities are much rarer. Nevertheless, if only a little of a metal is found in one pegmatite, others in the same region may be investigated carefully in the hope that a worthwhile deposit, or a group of deposits spaced sufficiently closely to be mined together, can be found. In some countries, pegmatites are important sources of gems such as emerald, sapphire, and topaz. Although pegmatites are common in Canada, important deposits of gems have not yet been found in this country.

Pegmatitic deposits have been studied and tested intensively in the region extending from Georgian Bay to Val d'Or, Quebec, in southeastern Manitoba, and in the region east of Yellowknife. A large lithium deposit is being mined in western Quebec. Deposits of pegmatitic granite and syenite were mined on fairly large scales for uranium near Bancroft, Ontario. Many small pegmatite deposits were mined for feldspar and mica in southeastern Ontario and southwestern Quebec, including one near Mattawa, Ontario, which contained unusually large and valuable crystals of muscovite.

Metasomatic Deposits

Deposits containing minerals formed at high temperatures and pressures commonly occur at the contacts between plutons and invaded rocks, or in the invaded rocks not far from a plutonic contact. Some such deposits appear to have resulted from metamorphism only, but many contain elements that appear to have been introduced by fluids injected from the plutonic body. Various authors have called deposits of this general class 'metamorphic', 'metasomatic', 'pyrometasomatic', 'contact metamorphic', and other names all having nearly the same meaning. They are here called *metasomatic* because it is a short name, because many geologists restrict 'metamorphism' to alteration without the introduction of additional material, and because many deposits of the kind under discussion occur in the general vicinity of contacts rather than right at them.

During the emplacement of metasomatic deposits, water, silica, sulphur, iron, magnesia, or other compounds or elements from the intrusive body apparently entered pores or fractures in the invaded rock and reacted with it to form minerals like garnet, diopside, and epidote. *Skarns* were produced if lime–silicate minerals formed. Other deposits lacking such minerals show many of the other characteristics of skarn. The compositions of the intrusive and of the invaded rocks are important factors in determining the character and extent of the alteration. Limestone and dolomite, for instance, are particularly susceptible to alteration of this kind, and granitic intrusives commonly cause the alteration. Metasomatic deposits are generally irregular in outline because the alteration proceeded farthest along favourable bands of rock or along zones of fracturing, whereas resistant patches of rock were only slightly altered. Gradations between metasomatic and pegmatitic types are common, even within a single deposit. A special type of metasomatic deposit occurs in fenites commonly associated with alkaline igneous rocks and carbonatites.

Minerals containing iron, copper, zinc, lead, gold, tin, tungsten, molybdenum, or manganese are sufficiently abundant in some metasomatic deposits in certain countries to form orebodies. Some are large and important, but as a rule they are small and difficult to mine because of their irregular shapes and the erratic distribution of the ore minerals. In Canada, deposits of magnetite in skarn have been or are being mined in British Columbia, Ontario, and Quebec. Deposits of nepheline syenite near contacts between granite and limestone, and of talc in dolomitic limestone near a body of granite probably belong to the contact metasomatic class. All are in southeastern Ontario. Pegmatitic deposits mined for uranium near Bancroft, Ontario, have metasomatic phases. Gold deposits in skarn were mined for many years at Hedley, British Columbia. A large copper deposit in Gaspé, Quebec, contains chalcopyrite and molybdenite in a skarn zone in shale and limestone.

Open-space Fillings

Veins of an infinite variety of sizes and shapes and of many mineral compositions are common in many parts of Canada. Particularly numerous are quartz veins, lenses, and stringers. Most are entirely quartz or contain insignificant amounts of other minerals, but others are entirely ore or contain ore shoots. Most are valuable for free gold or gold-bearing sulphides, but some are mined entirely or partly because they contain silver, lead, copper, uranium,

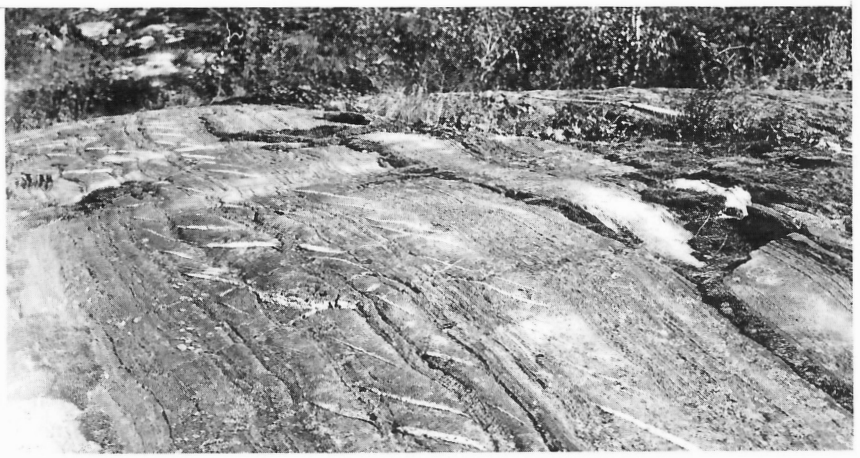

Plate 35
Gash quartz veins in brittle quartzite, and absent in alternating beds of more plastic argillaceous rock. This illustrates the occurrence of quartz veins in "competent" beds, which may happen on much larger scales.

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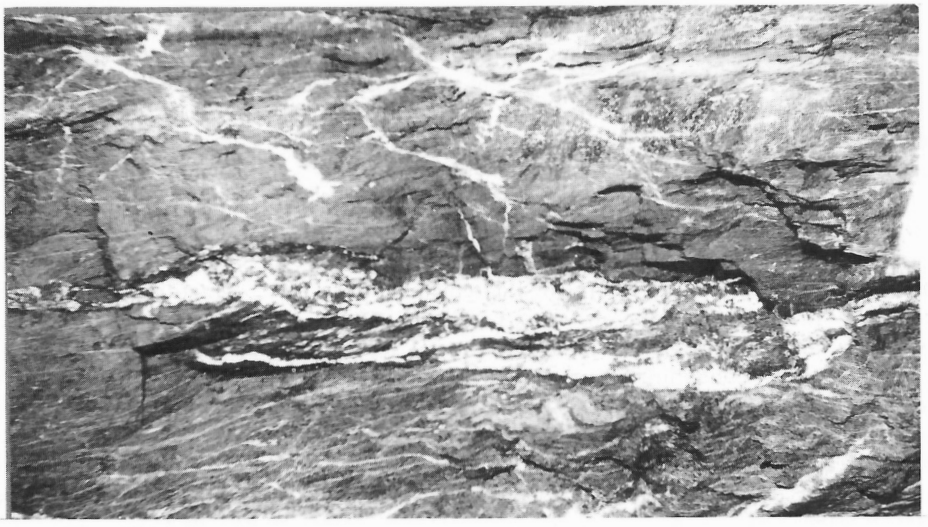

Plate 36
Vein quartz (white) replacing chlorite schist.

V. Dolmage 64070

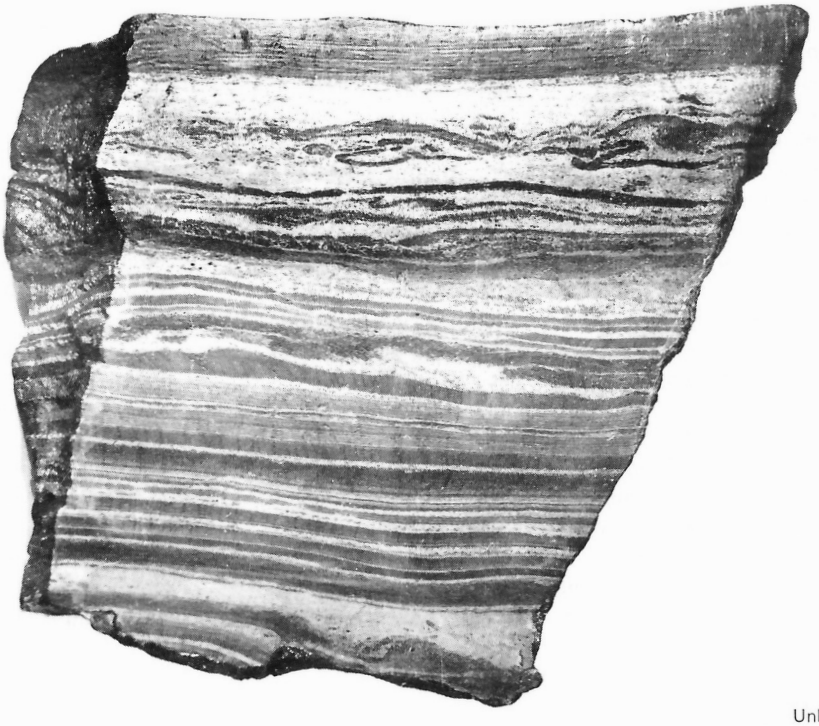

Plate 37
Stratiform galena, sphalerite, and other sulphide minerals (white to grey) replacing beds of sedimentary rock (unreplaced rock shown in dark grey and black), Sullivan Mine, B.C. Approximate size.

Unknown

or other metals, or minerals such as fluorite. Many breccia fillings have some of the tabular and other characteristics of veins, and others form pipes, chimneys, and less regular bodies. Some disseminations related to minute fractures have some of the characteristics of fillings.

The Nova Scotian goldfield, an important early producer, contains numerous quartz veins that lie mainly along the bedding of sedimentary strata, particularly as 'saddle veins' on the crests of anticlines and domes. Gold-bearing quartz veins and other deposits of the general vein class are abundant in other parts of Canada and have contributed much of Canada's gold output.

Calcite veins containing a variety of minerals are important sources of silver at Cobalt, Ontario. Veins and other transgressive deposits of various kinds have been worked extensively in British Columbia and Yukon Territory. Veins and breccia fillings in faults formed the rich radium–uranium ore mined at Great Bear Lake.

Replacement Deposits

Many deposits doubtfully classed as replacements exhibit evidence of this process, but may have resulted mainly from the filling of cavities, fractures, or dilatable fractures that are no longer visible because of the mineralization. Most authorities regard the large Sullivan lead–zinc deposit as a classic example replacement. The banded and contorted ore, shown on Plate 37, is present mainly in interbedded argillite and siltstone. Its most abundant metalliferous minerals are galena, sphalerite, pyrrhotite, and pyrite. Replacement lodes along fissures, containing gold, chalcopyrite and other sulphides in gangue composed of quartz, calcite, and altered wall-rock formed the rich orebodies at Rossland, British Columbia.

Lead–Zinc Deposits in Carbonate Rocks

Concordant, stratiform, and breccia deposits of galena and sphalerite in limestone and other carbonate rocks supply much of the world's lead and zinc. Leading examples form the 'Mississippi' or 'Tri-State' deposits in United States, many of which are described as replacements. Despite long study, these are regarded by some authorities as essentially syngenetic deposits that were modified by metamorphism or circulating groundwater, and by others as epigenetic deposits related in some way to plutonic activity.

The leading Canadian examples are those of the Pine Point area south of Great Slave Lake. There disseminations, crusts, and vug-fillings occur in Devonian dolomite that may have replaced a limestone coral reef. Various theories suggest that the deposits were formed as syngenetic sediments, as concentrations from smaller amounts of lead and zinc contained in the sediments and mobilized by circulating, cold groundwater; by leachings from deeper seated rocks by warmed artesian groundwater; and by solutions expelled from deep-seated magma. One theory explains the precipitation of metals as being facilitated by processes related to the origin of petroleum.

Shear Zone Deposits

Large shear zones containing massive and disseminated sulphide deposits or gold-bearing quartz are mined in several parts of Canada. The Britannia deposits in British Columbia are large, lenticular, sheet-like bodies containing quartz, pyrite, and some sphalerite that were brecciated and impregnated with chalcopyrite. Chalcopyrite and gold are obtained from several quartz–carbonate bodies in shear zones at Chibougamau, Quebec. Gold orebodies at Yellowknife, Northwest Territories, consist mainly of quartz in chloritic shear zones as wide as 200 feet.

Massive Sulphide Deposits

Concordant, strata-bound sulphide deposits are commonly associated with volcanic rocks or volcanic and sedimentary sequences. Although most discoveries of this kind contain only pyrite or pyrrhotite with little or no other metalliferous minerals, many also contain enough chalcopyrite, sphalerite, and, generally, other minerals to be among the most important classes of Canadian ores. Although most of these orebodies are massive or fairly massive, some contain disseminated parts, and at some mines where more than one orebody is worked, some may be massive and others disseminated. At some deposits evidence of minerals replacing rock or other minerals can be observed but, in general, the relative roles of open-space filling and replacement are doubtful.

Most deposits of this class have been found in areas containing plutonic as well as stratified rocks, and until recently were generally regarded as related genetically to plutonic activity which took place after the principal folding and faulting in the areas. Studies during the last few years have caused many geologists to consider that the deposits were concentrated from metals that were carried by lava flows, and that the concentration occurred at essentially the same time as the vulcanism. Several examples of deposits of this kind, containing copper, zinc, and other metals in the Timmins, Noranda, and Matagami areas, lie along contacts between rhyolite and related rocks overlain by andesite and related rocks (*see* Fig. 10). Structural features of some of these deposits, which were difficult to understand on the assumption that the ores were formed after the main structural disturbances, are explained more readily if the deposits were formed horizontally and later tilted by folding.

Disseminated Deposits in Siliceous Rocks

Disseminations of sulphide minerals in stocks composed of salic rocks, such as granite and granodiorite, form an important class of deposits which is now receiving increased attention in this country because deposits of lower grades are being mined. Chalcopyrite deposits of this kind are particularly notable, and disseminations of molybdenite and other sulphides are also found.

Disseminations of chalcopyrite and other minerals forming large low-grade orebodies in southwestern United States are commonly known as 'porphyry coppers', although

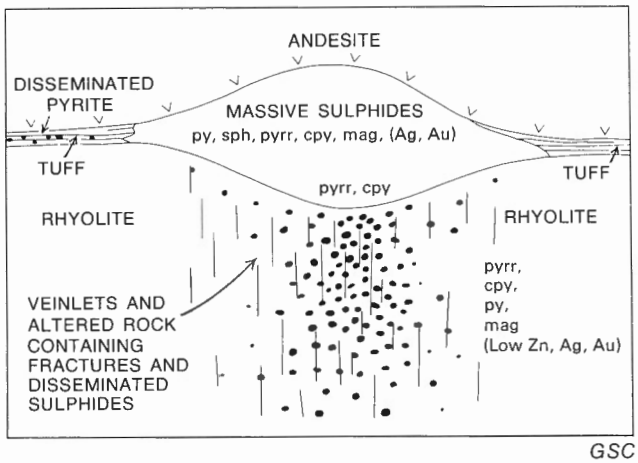

Figure 10. Example of mineral deposit apparently related genetically to its enclosing volcanic rocks. This is, in general, a fairly common spatial relationship in the Canadian Shield. Zoning is illustrated by the following symbols: py (pyrite), pyrr (pyrrhotite), cpy (chalcopyrite), sph (sphalerite), mag (magnetite), Ag (silver), Au (gold), Zn (zinc). From drawing by S. M. Roscoe.

they occur in porphyritic and non-porphyritic salic plutons and to some extent in the surrounding rocks, all of which are commonly fractured and altered. Most dissemination seems related to the filling of fractures, but some evidence of replacement and metasomatism are reported. The upper parts of the deposits contained richer supergene deposits. Porphyry copper has largely become a term of mining engineering, and is applied to large, low-grade, evenly disseminated copper deposits in rocks of different kinds.

Several orebodies of the general porphyry–copper class are known in various parts of Canada. The Copper Mountain deposit in southern British Columbia contains bornite disseminated in a stock having zones of different compositions from gabbro to syenitic pegmatite. Farther north the Bethlehem deposit contains chalcopyrite, bornite, and molybdenite in brecciated granite, part of which is partly porphyritic. Diamond drilling at the McIntyre gold mine at Timmins, Ontario, revealed an orebody composed of disseminated chalcopyrite with some tennantite and molybdenite, in a mass of quartz–feldspar porphyry.

A large pyrite–chalcopyrite–molybdenite deposit in Gaspé is partly disseminated in granite and partly skarn.

Sedimentary Deposits

Normal Sediments

Simple sedimentary deposits are syngenetic accumulations interlayered with sedimentary rocks and formed contemporaneously with them. Laboratory experiments and the examination of samples obtained from present sea-bottoms leave no room for doubt that typical sedimentary 'iron-formations' and some manganese deposits are consolidated marine sediments, although other kinds of iron-formation may have been caused by replacement or metamorphism. Some deposits of non-ferrous metals, such as a large body in Europe containing copper, lead, and zinc, have generally been considered to be purely sedimentary, but other origins have recently been suggested. One theory for the formation of these and partly similar deposits is that the metals were dissolved from nearby sediments by brines heated from their passage through warmer strata and deposited where chemical conditions were suitable. If such effects took place after the sediments were consolidated into rock, the deposits would be epigenetic, but if they took place in unconsolidated sediments they might be regarded as part of the sedimentary process and so be syngenetic. Another theory suggests that seawater was enriched in metal content by springs of hydrothermal origin.

Sedimentary deposits have been called 'bedded deposits' by some writers, but others have used the term 'bedded' for any stratiform deposits regardless of sedimentary or replacement origin, and still others have restricted the term 'bedded' to sedimentary deposits that are themselves stratified internally. To avoid confusion the term 'bedded' is not used in this publication, and 'stratiform' is used to describe deposits having the general appearance of strata, regardless of sedimentary or replacement origin.

Clay and Marl

Clay is very fine grained or 'colloidal' material from the erosion of rocks containing abundant aluminum and silicon, carried in suspension in water, and deposited in the beds of rivers, lakes, and seas. Clay is plastic when wet and hardens when fired. Many of the abundant clay deposits in Canada were laid down in glacial lakes toward the end of the Pleistocene period.

Marl is an earthy form of calcium carbonate deposited in lakes by the action of certain plants growing in the water. Marl is not of great importance but is sometimes used locally as a soil conditioner. Several years ago in Alberta a deposit was worked for making cement.

Evaporites

A valuable class of deposits including common salt, potash (sylvite), gypsum, and anhydrite is formed by the evaporation of seawater or saline lakes. Seawater is evaporated in shallow bays and depressions in tidal flats, particularly in warm regions. In some places mixtures of salts are precipitated either together or in successive bands of different composition, perhaps interspersed with ordinary sediments. At some non-Canadian localities certain unconsolidated salts are gathered soon after evaporation. Other deposits, including many of those in Canada, were formed in previous geological periods and incorporated in sedimentary formations. Some such deposits are mined underground and others are extracted from brine.

Unconsolidated Placer Deposits

Placers (alluvial deposits) are concentrations of metalliferous minerals or gems in sand or gravel. They are discussed at greater length in Chapter 16 for readers especially interested in the subject, but the following is intended for more general study.

The word 'placer' is believed to have been derived from an old Spanish word meaning a 'deposit' or a place where a deposit is mined by washing. The minerals that form placers are usually heavy, resistant to chemical decomposition or solution, or so hard and tough that they do not wear down easily or split into smaller and smaller fragments. The most important placer minerals are, therefore, gold, platinum, cassiterite, ilmenite, diamonds, and rubies. Magnetite that existed originally as an accessory mineral in igneous rocks is concentrated in considerable quantities to form 'black sand', but such placers are rarely large and rich enough to be workable as sources of iron. Garnets are common in placers and are often mistaken for rubies.

Several requirements are necessary for the formation and preservation of placers. First, there must have been a supply of suitable minerals dispersed in the bedrock or contained in mineral deposits. Secondly, weathering must have gone on for a long time. Thirdly, conditions must have been favourable for concentration. This last requisite usually demands a region of hills or mountains to provide streams with sufficient velocity to carry off the lighter products of erosion. The most favourable conditions exist in areas where erosion was long continued, reducing the land surface to a fairly level state, after which the surface was uplifted and dissected by streams that concentrated the residual minerals lying on the ancient surface. Lastly, the placers must have been preserved; many placers were doubtless destroyed by later erosion, including glaciation. The effects of glaciation probably account in part for workable placers not having been found in the Canadian Shield, although the rocks of the Shield contain many primary gold deposits, the weathering of which may have produced placers that were destroyed by glaciation. The presence of placers in glaciated parts of the Cordilleran region is explained by the rugged topography that apparently protected many placers from destruction by preventing glaciers from scouring evenly all parts of the surface.

Some placers are formed on the slopes below outcrops of mineral deposits. These are in the first stage of placer formation and generally are not large because the placer minerals are soon washed into streams. Other placers are formed along beaches where waves erode rocks or rework and concentrate glacial gravels or sands containing small amounts of valuable minerals. Most placers, however, occur in stream gravels, generally gravels deposited in ancient channels rather than in the beds of present streams. The valuable minerals are generally concentrated on or near bedrock at the bottom of the channel, and may be lodged in crevices in bedrock; in some placers, however, 'paystreaks' may occur within the gravel some distance above bedrock. Most valuable placer minerals are in fairly small grains, but in the case of gold, nuggets may be present. Almost all workable Canadian placers are, or have been, gold ones in Yukon Territory and British Columbia (the words 'have been' are included because most known significant placers have been mined). Most placers are or were of interglacial or postglacial ages, but some are known or believed to be or have been Tertiary. In rare instances placers have been found in Tertiary gravels overlain by volcanic rocks. Many placers are or were overlain by glacial drift, a condition that rendered their discovery and mining more difficult than it would be with placers at the surface.

Consolidated Placer Deposits

Placers that were formed during early geological periods, if they were not destroyed by erosion, became consolidated into beds of conglomerate or sandstone containing deposits of magnetite, gold, or other minerals. Certain deposits have undoubtedly been formed in this way. Several other important deposits may have so originated but the evidence regarding them is not conclusive. For example, the gold ores in Precambrian conglomerates in South Africa, which are the world's principal source of gold, were at first believed unquestionably to be consolidated placers. It has been shown recently, however, that at least some of the gold and other metalliferous minerals that accompany it may have been deposited after the rock was consolidated. As can well be imagined, the importance of these deposits has caused endless investigation of this problem, but despite the efforts of many eminent authorities it is not yet certain whether the ore minerals were introduced hydrothermally to form deposits that have only an accidental resemblance to placers, or whether the gold passed through a placer stage and was later dissolved and slightly rearranged.

Much the same problem arises if one attempts to explain certain other deposits of gold, uranium, and other metals including the large uranium deposits of Elliot Lake, Ontario. Deposits that are definitely of detrital origin are not difficult to distinguish if the ore minerals are not too finely dispersed to be seen with a microscope, because detrital grains are either rounded from the wear of transportation by water or are split into angular fragments, whereas minerals introduced by solutions show interlocking crystal structure or other characteristic microscopic textures and relationships. On the other hand, a deposit that once existed as a placer and then was recrystallized, and whose ore minerals in this process may also have been moved a short distance from their resting place in the placer stage, would be difficult or impossible to distinguish from one whose ore minerals were deposited from fluids percolating through gravel.

Laterites and Other Residual Deposits

Laterites

Unconsolidated residual deposits of iron and aluminum called *laterites* are formed by the weathering and carrying away of some constituents and a resulting concentration of others that are sometimes more desirable. This takes place mainly in tropical and sub-tropical countries where weathering has been deep and prolonged. Deposits of this kind are not common in Canada because of climatic conditions and probably also because most of those that may have existed have been destroyed by glacial erosion.

Other Residual Deposits

Consolidated residual deposits of iron minerals are more important in this country. Goethite and hematite deposited as pockets of residual minerals, which resulted from deep weathering of older rocks, were formerly mined for iron near Londonderry, Nova Scotia. Hematite–goethite ores now mined near Steep Rock Lake, Ontario, are believed to have been formed from accumulations of iron oxides on a Precambrian erosion surface.

Supergene Deposits

Distinctions between 'primary' and 'secondary' minerals were mentioned in Chapter 3, and different usages of these terms in connection with mineral deposits were discussed earlier in this chapter. To avoid confusion with other deposits that might be regarded as secondary, the term *supergene* is more appropriate for deposits changed by oxidation or other near-surface effects, without complete destruction of the altered part of the deposit. Thus only the upper part of a deposit may be supergene, in which case the lower part would be primary or *hypogene*. Some authorities use the term 'hypogene' only for those parts of certain deposits whose metal content was enriched by supergene concentration of valuable metals or by the solution and removal of less valuable constituents. Such a distinction is not implied here.

Almost all metalliferous minerals lying at or near the surface are altered by the effects of surface water that attacks them and causes the formation of new ones, generally oxides or hydroxides (compounds composed of a metal plus oxygen or hydrogen and oxygen). Some minerals containing metals such as copper, iron, and uranium are readily attacked by surface waters, others are less susceptible, and a few like gold and platinum are so resistant that they do not form compounds in this way. Deposits containing supergene iron minerals have a characteristic rusty appearance and are called *gossans*.

Most supergene deposits found in Canada contain only small amounts of minerals such as limonite, malachite, cobalt bloom, and supergene uranium minerals, which extend for a few inches or feet below the surface, but in exceptional circumstances, such as in the unglaciated or slightly glaciated parts of Yukon Territory, supergene minerals have been found in mines to depths of 100 feet or more. The mineral uranophane, believed to be supergene, was mined to a depth of about 1,000 feet near Uranium City, at the Gunnar mine where porous rock permitted circulation of water from a nearby lake. Misleading low copper contents resulting from leaching were reported to have extended to depths of more than 20 feet at the Brenda deposit in British Columbia. As a rule, the altered parts of Canadian deposits contain both supergene minerals and some of the original minerals, and although the total metal content is not exactly the same as in unaltered parts of the deposit it is usually not greatly different. Therefore, at most Canadian deposits the supergene effects have only a minor influence on the value of the deposit. As exceptions have occurred geologists are mindful of the possibility, particularly with respect to low-grade deposits. The main significance of supergene minerals in Canada to date has been that they are often important clues in prospecting for primary deposits. Small amounts of supergene minerals may stain a fairly large area and thus make detection of a deposit easier. Also, some supergene minerals are brightly coloured. In these connections three points should be remembered. Firstly, the supergene minerals may occur a short distance laterally from the unaltered deposit, not necessarily immediately above it. Secondly, many supergene minerals are soluble in water and may be removed from the actual surface of an outcrop by rain or other moisture; therefore, to find them, it is often necessary to hammer into an outcrop or specimen where they may be preserved as fillings in narrow fractures or cavities. Lastly, a very small deposit or a large one having an unimportant metal content may produce a spectacular display of supergene minerals; hence a conspicuous gossan or other supergene deposit does not necessarily indicate that an important primary deposit exists.

Industrial Deposits

Nonmetallic deposits and structural materials are commonly called industrial minerals or industrial deposits because they are generally used by industries in their mineral or rock state instead of for the extraction of one or more of the elements forming a mineral, as is usually the case with metallic minerals. The term 'industrial' is used somewhat flexibly, however, as some nonmetallic minerals are used for extraction of such elements as chlorine and fluorine, and pyrite is sometimes classed as an industrial mineral when used to produce sulphur.

Industrial deposits accounted for about 20 per cent of Canadian mineral production in 1967. The value of the output of structural materials (clay products, cement, lime, sand, gravel, and stone) was $469 million. The value of nonmetallics totalled $414 million, to which asbestos contributed $163 million, potash $77 million, and sulphur $76 million.

A fundamental difference between prospecting for and appraisal of industrial deposits and that for metallic deposits exists because industrial deposits are used for their physical rather than their chemical properties. The difference is that, because the emphasis is on physical properties, specifications and sizes are usually the critical factors, instead of assays and sizes, which are so critical when dealing with metallic deposits. Specifications are usually rigid, even for such everyday commodities as sand and gravel. Also, most nonmetalliferous materials have much lower unit prices than metals, which generally dictates that commercial deposits be near transportation and markets. For these reasons nonmetalliferous deposits are usually sought by geologists, engineers, or conventional prospectors for a company desiring a particular commodity having particular specifications, in a particular area. Nevertheless, some independent conventional prospectors have gained a sound knowledge of structural or nonmetallic deposits, and there is no reason why others should not do so. Prospectors specializing in metallic deposits should not ignore the possibility of encountering worthwhile industrial deposits, and can gain an



R. W. Boyle

A. Gossan in sulphide orebody, Bathurst, N.B. The brownish supergene material in the steeply dipping deposit is partly residual alteration which probably took place in Tertiary time. Overlying this is till cemented and stained by iron minerals deposited by water which circulated through the deposit beneath. The horizontal band above the surface of the pond is merely staining caused by changes in the pond's level.

Plate 38



H. R. Steacy

B. Specimen illustrating an example of staining by secondary uranium minerals derived from the alteration of primary minerals such as uraninite. Here thin films of yellow uranophane are seen staining pegmatitic granite. The black mineral is biotite. Five-sixths natural size.

idea of their possibilities from the notes on them in Chapter 15.

Structural materials are unconsolidated deposits and rocks of some of the kinds described in Chapter 2 but having especially suitable qualities. Nonmetallic deposits are concentrations belonging to some of the classes discussed earlier in this chapter. Most are concordant, but many minerals such as asbestos, barite, and fluorite are mined from veins and other transgressive deposits.

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MINERAL FUELS

The *mineral* (fossil) *fuels* are coal, petroleum, and natural gas. They are called mineral fuels because they are produced from rock formations, but they are not minerals as defined in Chapter 3.

Coal, petroleum, and natural gas accounted for about 30 per cent of the total value of Canada's mineral production in 1967. This amounted to about $84 million for coal, $886 million for petroleum, and $198 million for natural gas. Despite the great importance of these products only a little space is devoted to them in this publication because there is not much demand for additional coal discoveries at present, and because prospecting for petroleum and natural gas is so specialized that it is almost beyond the scope of this book. The following passages are, therefore, only brief outlines of these topics to provide general information for those who are interested.

Coal

Coal is formed from an accumulation of vegetable matter from previous geological periods. Every gradation between hard coal, soft coal, woody coal, and peat has been recognized, and many coals contain the imprints of leaves, ferns, and other vegetable forms. The vegetation grew in swamps of fresh or brackish water, accumulated at the bottoms of these basins or floated into concentrations, and turned into a peaty substance. Subsequent burial by sand or mud protected it until, layered between sedimentary rocks, it became gradually converted into coal through the agencies of pressure and heat.

Because of this origin, coal is found as seams or beds in sedimentary rocks, such as shales and sandstones, which were laid down in fresh or brackish water. Sedimentary rocks of the Carboniferous and Cretaceous ages contain the most important of the world's deposits of hard coal, and beds of Tertiary age yield most of the world's lignite.

The three main types of coal, with their distinguishing features, are as follows.

Lignite: brownish black colour; plant and woody structure commonly apparent; high moisture content causes disintegration upon drying.

Bituminous: black, brittle, with alternation of dull and lustrous layers; well-jointed, breaking into cubes or rectangular blocks; burns with smoky yellow flame.

Anthracite: black, hard, brittle, with shiny, conchoidal fracture; ignites slowly and burns with a smokeless blue flame.

Several intermediate ranks such as subbituminous and semianthracite are recognized. The principal chemical differences in the progression from lignite to anthracite consist of a relative increase in the carbon content and a relative decrease in volatile constituents and moisture. A geologically ancient coal will probably, over a long period, have been subjected to sufficient pressure and heat to transform it to coal of high rank or perhaps to graphite. The higher pressures and temperatures that accompany intense folding of beds is very important in producing changes from lignite towards anthracite.

Folding of coal seams increases their chances of outcropping. The mining of intensely folded or faulted seams, however, is usually more costly than the working of unbroken, only slightly tilted beds.

The character of the rocks enclosing a coal seam may greatly affect the cost of mining. A roof of weak shale may require much support, yet one of strong sandstone may not be suitable for some underground methods of mining. The character of the roof is also very important in strip mining.

Most of the coal mined in Canada is bituminous. It is used mainly for heating and for production of steam. Lesser amounts are used in the manufacture of coke and artificial gas. Special grades of coke are used extensively in the production of iron and steel from iron ore. The principal Canadian coal deposits are in the eastern and western parts of the country, very large mines being worked in Carboniferous formations in Nova Scotia and in Mesozoic formations in British Columbia and Alberta. Tertiary coals are also mined in western Canada.

Canada has many producing coal mines and large known reserves of coal, but the coal mining industry is faced with difficulties. One reason for this is that coal must compete with fuel oil and natural gas, which are preferred for some uses; in fact, some authorities believe that the long-term outlook for coal is as a chemical raw material rather than as a fuel. Another reason is that many of the industrial

plants that require coal or coke are situated in the interior of Canada, far from the principal coal mines which are in the eastern and western parts of the country; this interior market is served largely by coal from the United States. Nevertheless, some large thermal-electric plants use coal, and demand exists in some areas for coal suitable for making metallurgical coke. Contracts for supply of coking coal to Japan have improved the outlook for some western deposits.

Because of the conditions outlined above it is not likely that general prospecting for coal would be worth while in Canada in the near future, although some authorities are optimistic regarding the long-range outlook. There are no doubt special cases where a coal-mining company, knowing of a demand for a certain type of deposit in a certain region, would send a qualified man to search. The average prospector, however, if working in areas where coal may be found, should note any new occurrence of coal he sees while prospecting for other minerals, in case he could interest someone in it; or if he knew that a local demand existed in a place near outcrops of formations suitable for the occurrence of coal, he might search for a deposit.

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Petroleum and Natural Gas

Petroleum is more familiarly known as 'crude oil' or simply 'oil'. It is customary to distinguish 'natural gas' from other gases, but for the purposes of this discussion it can be assumed that the word 'gas' refers to naturally occurring combustible gas. Oil and gas are vital to our present way of life, particularly because of the great demand for gasoline, and Canada is fortunate in having large supplies, mainly in the Great Plains region. Canada at the end of 1966 had recoverable reserves of liquid hydrocarbons estimated at about 9 billion barrels (not including the Athabasca oil sands) and proved recoverable reserves of natural gas of some 44 trillion cubic feet. Canada's output of liquid hydrocarbons during 1968 averaged 1,190,000 barrels per day. Her production of crude oil supplied 58 per cent of the requirements of Canadian refineries. Natural gas production amounted to about 4.45 billion cubic feet per day. Extensive pipe-line systems have been built to carry oil and gas westward to the Pacific coast, southward into the United States, eastward into Ontario for oil, and into Quebec for gas. Additional pipe-lines will doubtless be built, but because of the great distances involved it may be more economical to continue importing oil for certain parts of the country, even if the ability to produce is much increased. It would also be impractical to extend gas lines to all communities.

Origin of Oil and Gas

Petroleum and natural gas are allied substances of organic origin accumulated under special conditions in porous beds in the earth's crust. The organic materials were deposited in past geological ages in bodies of water, together with the sand, silt, and mud of normal sediments such as are brought down the rivers of today to be deposited in the sea. No oil or gas has been found in rocks of Precambrian age, presumably because of lack of suitable living organisms during Precambrian time.

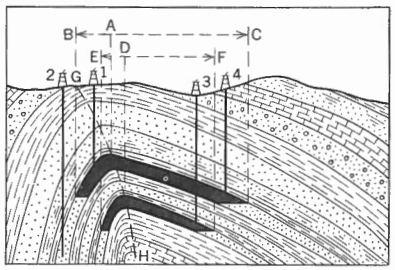
Organic materials long exposed to air or water decompose, but salt water retards the decomposition and, if sedimentation is sufficiently rapid, organic matter is trapped in the sediments. Bacteria present in the sediments are believed to aid in the freeing of waxy and fatty matter from organic material, and this action takes place best in salt water. This probably explains in part why oil and gas are associated with marine rather than freshwater sedimentary formations. Sands and gravels may contain little organic matter, but the finer particles of clay have about the same weight as particles of organic matter; therefore, dark shales, particularly those of marine origin, are considered the most favourable source beds for oil and gas. Some limestones may also have a high content of organic substances, especially those formed in fairly warm seas. The organic substances trapped in shales and limestones are slowly subjected to heat and pressure and changed into gas and small globules of oil, which are at first widely scattered and must migrate into suitable concentrations and be trapped to form commercial deposits.

Porosity and Permeability

Nearly all rocks contain some open spaces between the constituent grains. If these 'pore' spaces are sufficiently close together and connected the rock is permeable and allows the slow passage of liquids or gases through it. The most permeable rocks are sandstones, some coral limestones, and some dolomites, particularly those formed from limestones by replacement of some of the lime by magnesia, with a decrease in volume and some consequent fracturing. Even shales, the least permeable of the sedimentary rocks, contain very small pores through which liquids pass by capillarity. When oil and gas get into rocks that are sufficiently porous, or are fractured or faulted, they migrate slowly upward until the surface is reached or until relatively impervious rock prevents further movement.

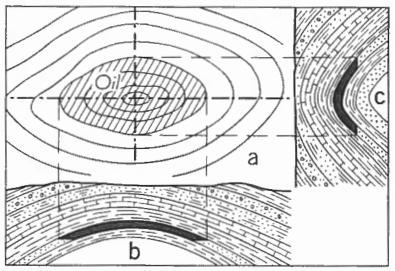
Traps

There are many kinds of structural and other traps, the simplest being anticlines and domes, as illustrated on Figure 11 A and B. Under ideal conditions the gas, because of its lightness, will fill the porous beds at the crest of the fold and will be underlain on the flanks by oil, which in turn is lighter than the water that fills the pores in the lowest part of the structure. There may be departures from this sequence, even in simple anticlines. For example, natural gas moves with much greater ease than oil and, consequently, structures are found that contain only gas. Not all anticlines, even in an oil-bearing region, necessarily contain gas or oil, because water movements in the porous strata may be strong enough in some cases to flush an anticline, causing a migration of the gas and oil to another structure where the effect of water is less pronounced. Other types of traps are provided by faulting of a porous stratum



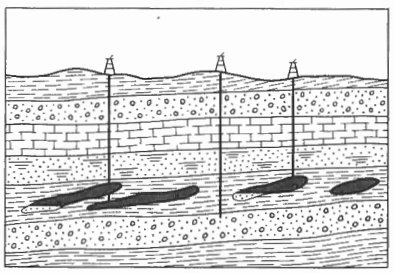
A

Simple asymmetric anticline with two oil-bearing strata; G H *shows change in dip of axis of the fold;* B C *width of productive area for the upper sand;* E F *for the lower sand. Axes of folds at* A *and* D *lie near the left edge of the productive area. Well No.* 1 *is productive; No.* 2 *is barren; No.* 3 *produces from upper and lower sand; No.* 4 *produces from upper sand.*



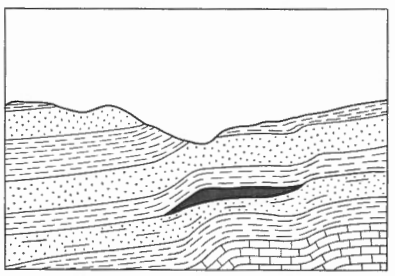
B

Dome structure; *illustrated in plan* a, *by contours representing the urface of the oil-bearing bed, and by vertical sections* b *and* c.



C

Lenticular deposits; *lenses (black) of coarse sand in oil-bearing shales serve as local centres of concentration.*



Terrace structure; *black indicates an accumulation of oil.*

GSC

Figure 11
Diagrams of oil-bearing structures (A, B, and C after L. C. Uren).

adjacent to an impervious one, by a lenticular porous stratum in impervious beds (*see* Fig. 11C), by 'terrace structures' (*see* Fig. 11D), and by large coral reefs.

Thus, the requisites for the accumulation of oil and natural gas are the presence of source rocks such as oil-bearing shale or limestone, the presence of porous strata to form a reservoir, the presence of suitable structures or other traps, and a covering of impervious rock such as shale to prevent further upward migration and loss. The source rocks may not be exposed at the surface, and may not be close to the trapping structure, but careful study of the strata over broad areas may indicate their presence far beneath a favourable structure. The structures themselves can be detected by careful stratigraphic and structural mapping and by geophysical surveys and there may occasionally be an oil seep at the surface nearby, but the presence of an

accumulation of oil or gas can only be proved by drilling expensive wells, often to depths of several thousands of feet.

Oil-shales and Sands

Outcrops of shale containing organic hydrocarbon compounds are fairly common, and oil is produced from them in some countries by mining or quarrying the shale and distilling off the hydrocarbon. The hydrocarbon in these rocks is a residue left after the more volatile parts of oil-bearing shales were driven off long ago by natural processes involving heat and pressure. Several such occurrences are known in Canada, mainly in the Maritime Provinces and British Columbia, but they have not been considered workable; the better deposits may become valuable at some future time.

Canada also possesses a unique type of occurrence found over a large area near Fort McMurray in northern Alberta. The deposit consists of bituminous material in unconsolidated sand of Cretaceous age (*see* Pl. 39) that rests on Devonian limestone. The bituminous matter represents oil from which the more volatile material has been driven off by natural processes. It is not certain whether the oil was originally in the underlying limestone or in the sands. Commercial production of oil from this large deposit, estimated to contain recoverable reserves of some 300 billion barrels, was begun in 1967.

Prospecting Possibilities

Prospecting for oil and gas is a difficult and complicated matter. Seepages of oil or gas sometimes give a clue for a successful discovery, but prospecting depends mainly on detailed studies of the rocks and structures exposed in areas where the geology is favourable in a general way, on detailed studies of cuttings and cores of rock from wells already drilled in a district, and on special geophysical studies that assist greatly in interpreting the structures at depth. Favourable sites are explored by drilling very costly wells; a few wells in Alberta that reached depths of about 2 miles cost about $1,000,000 each to drill, and many shallower ones cost more than $100,000. Despite the most thorough preliminary studies, many wells are drilled unsuccessfully, because there was no oil or gas in the structure, or they were not present in commercial quantities, or the well was not in quite the right place, or the structure changed with depth.

Prospecting for oil and gas is, therefore, a highly specialized undertaking beyond the scope of the ordinary prospector. It is almost entirely carried out by geologists or geophysicists employed by oil companies, but is occasionally undertaken by independent professionals. The literature on the subject is extensive and well known to those engaged in the work, so it is unnecessary to discuss the details in a publication of this kind.



C. S. Lord 86059

Plate 39. Oil sand, Fort McMurray, Alberta, and an experimental machine for mining it.

A prospector searching for metals or minerals in regions containing marine sedimentary rocks might be alert for seepages of oil or gas and for occurrences of oil-shales or sands. It should be remembered, however, that many reported oil seepages are nothing but an iridescent film on water, caused by iron compounds or decomposed vegetation, and that many gas seepages consist of coal gas or marsh gas instead of the important kind of gas that is related to oil.

In some parts of the country oil and gas rights accompany the land rights, and in other parts they are reserved to the Crown. Claims are not staked for oil and gas, but leases may be obtained from the owner of the land or from the provincial or territorial government concerned.

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5

outline of the geology of canada

Rocks of many kinds, ages, and structures underlie different areas of this country as its 4 million square miles span parts of all the main geological regions of North America. This variation in geology is responsible for Canada's diversity of mineral resources, topographic forms, and scenery, as topographic effects are controlled by underlying geological conditions. Differences in geology and climate are largely responsible for Canada's variations in forest and agricultural resources, and in land uses and settlement. Although local geological details are generally complex the country is divisible into distinct geological regions, most of which are divisible into sub-regions of various ranks and sizes. At least limited knowledge of these is essential to prospecting because their known and potential mineral resources differ greatly. Although the main regions and some of their principal sub-divisions were established many years ago some have had different names in different publications. Other sub-divisions have still to be established.

This chapter summarizes the geology of Canada for those who are unacquainted with the subject and provides a brief, up-to-date review for persons who have studied the subject before. Obviously, only a short summary of this large topic is possible in a publication of this kind. The main regions and their sub-divisions are outlined, their general geological and structural features are described, and some of the kinds of mineral deposits that are or might be found in them are discussed briefly. More detailed discussions of these subjects, together with many references and illustrations, are included in "Geology and Economic Minerals of Canada" which is recommended as a text and reference book intermediate between this chapter and publications on particular areas or topics.

Canada is divided geologically into a *shield* region, four *platform* regions, three *orogens*, and three *continental shelves*, as shown on Figure 12. The *Canadian Shield*, which underlies about half the total area of the country, is a roughly shield-shaped region in which Precambrian rocks are exposed or covered by overburden. This region, which has been relatively stable since Precambrian time, forms the nucleus of the continent. The platform regions surrounding much of the Shield are underlain by flat-lying Paleozoic and younger strata resting on unexposed Precambrian basements formed of rocks generally similar to those of the Shield. The orogens are large elongate belts which, from time to time during the Paleozoic, Mesozoic, and early Tertiary, were affected by mountain-building (orogenic) disturbances with accompanying igneous activity and metamorphism. Series of geosynclines were developed in different parts of the orogens, some at different times, resulting in thick accumulations of sedimentary or volcanic strata, or both. In some parts many bodies of plutonic rocks were formed. The three orogens are the Appalachian in eastern Canada, the Innuitian in the Arctic, and the Cordilleran in western Canada. The rocks formed in them were folded, faulted, and uplifted at different times, commonly at two or more times in a single area, by orogenies. Erosion of the uplifted rocks has since carved the land surfaces approximately to the topographic forms now seen in the Appalachian, Innuitian, and Cordilleran mountains, except for some effects of glaciation. Coastal plains lie along parts of the Arctic and Pacific coasts, and continental shelves underlie parts of the Atlantic, Arctic, and Pacific Oceans.

Most of Canada was covered by glaciers during the Pleistocene period about 10,000 years ago. These glaciers scoured and removed much of the residual soils and placer deposits formed during Tertiary time, and abraded some of the bedrock at the surface of the land, which left streaked and polished rock surfaces and extensive accumulations of sand, gravel, and clay deposited by the glaciers themselves or by the waters melted from them as the climate moderated. The relative amounts of exposed rock and overburdened areas for the country as a whole cannot be estimated accurately because conditions vary from large areas of exposed rock in high mountainous regions to plains that are almost entirely covered by overburden. Another difficulty arises because rock outcrops in many areas are covered by moss or overhanging trees which prevent useful estimation from studies of air photographs. Experience has shown, however, that it is probably safe to say that overburden covers bedrock in more than 95 per cent of the land area of Canada as a whole.

Suggestions for Additional Reading

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This up-to-date and comprehensive description was written on the assumption that the reader has some knowledge of introductory geology, but readers who have studied Chapters 2 to 5 of this book should find *Geology and Economic Minerals of Canada* understandable and useful. It is accompanied by a series of new maps of Canada: geological, tectonic, glacial, magnetic, gravity, and mineral deposits.

CANADIAN SHIELD

Half of Canada is underlain by the Canadian Shield which is named for its shield-like outline, within which rocks of Precambrian ages are exposed or covered only by overburden. The Canadian Shield extends into the United States to form a large area south of Lake Superior and the

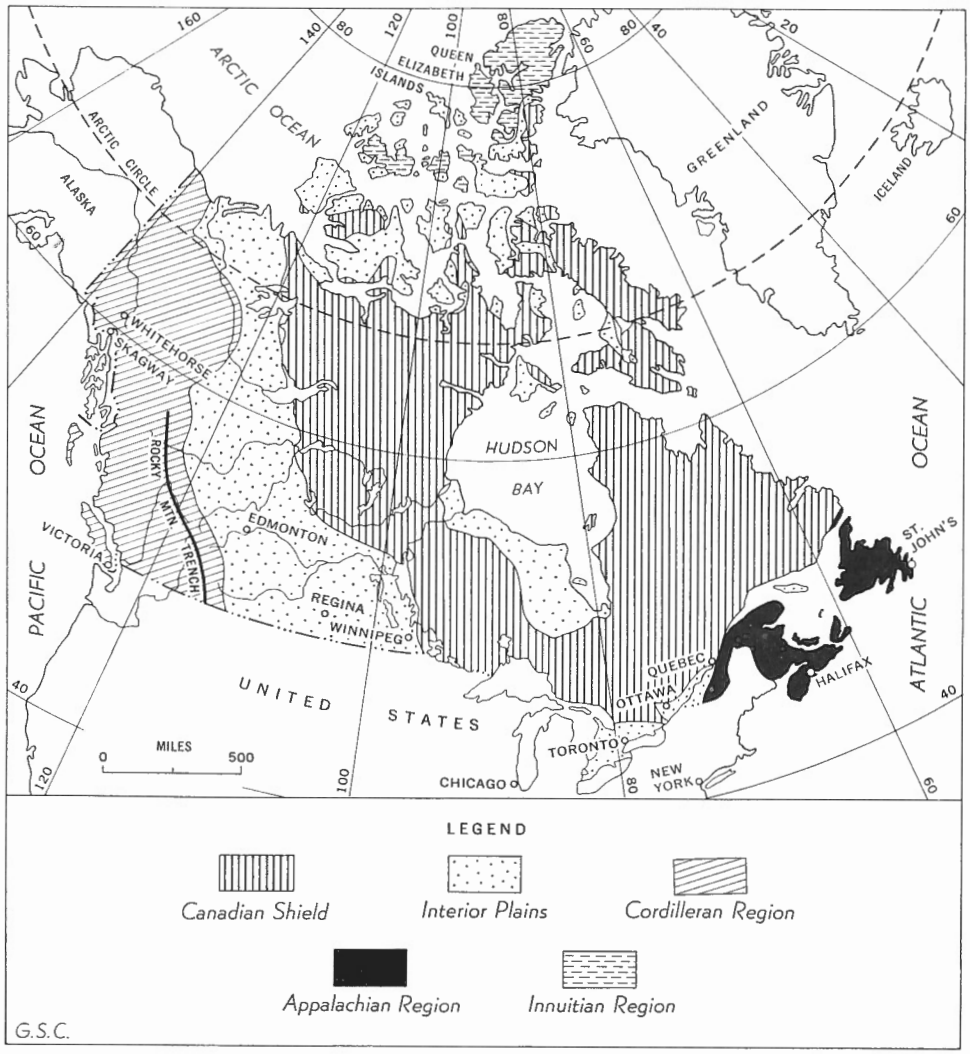

Figure 12
Main geological regions of Canada.

smaller Adirondack area in the state of New York. Rocks of the same general kinds and ages as those of the Shield slope gently under the younger strata flanking the Shield, and are exposed in patches called 'inliers' in the western Arctic, south of Hudson Bay, and in the Island of Newfoundland.

The Shield region has many resources and has been Canada's leading source of metals. It produces many industrial minerals, and because of its size and the many areas in which the geology is favourable, it has great potential for the discovery of additional economic mineral deposits. Forest products are derived from many parts of the Shield, its numerous rivers provide hydro-electricity, and the topography and scenery, which are controlled by the geology, combine with a temperate climate to make the Shield an attractive resort region.

The rock surface of the Shield is an ancient, undulating erosional surface dissected by younger valleys. It slopes toward Hudson Bay and has a general height of about 1,000 feet above sea level along its western margin in Saskatchewan and Northwest Territories. It is still higher in the Haliburton Highlands and Laurentians and along the Gulf of St. Lawrence, and mountains rise to 5,500 feet in Labrador and 8,500 feet on Baffin Island. The Shield has been fairly stable since the end of Precambrian time, except for uplifting in late Tertiary time, estimated at 300 to 700 feet, which caused valleys to be cut by rejuvenated streams. Changes in elevation also occurred after the glaciation of the Pleistocene period. Faulting took place along the southern border and near Boothia Peninsula at different times after the end of the Precambrian.

The rocks of the Shield represent at least five-sixths of geological time. The older rocks were formed during the *Archean* Eon and the younger during the *Proterozoic* Eon (*see* p. 26). A pronounced and widespread erosional surface (unconformity) estimated to have been formed about 2,390 million years ago separates Archean rocks from those of Proterozoic age. Sedimentary, volcanic, and plutonic rocks were formed at various times during each eon, volcanism being particularly active in Archean times. The rocks of many parts of the Shield were deformed by periods of mountain building (orogeny) which occurred at different times in different places, causing much folding, faulting, metamorphism, and granitization. The rocks of



C. S. Lord

Plate 40A. Part of the Canadian Shield north of the limit of trees, southern part of Keewatin District, Northwest Territories.



A. H. Lang

Plate 40B. View in the Canadian Shield, northern Saskatchewan.

some parts of the Shield must have been disturbed in these ways at several different times, but only the effects of the latest orogeny in a particular area are prominent. In many areas Archean rocks have been so altered by metamorphism and granitization that their earlier types and structures are unrecognizable. In other places metamorphosed Archean volcanic and sedimentary strata can be recognized and traced in fold belts, some of which probably represent very ancient geosynclines. Proterozoic strata are generally not metamorphosed so strongly as those of Archean ages. In several parts of the Shield thick successions of strata of Proterozoic age were deposited in geosynclines and later folded in long belts. In other places large, relatively thin sheets of flat or gently tilted Proterozoic strata cover older rocks.

Most of the Shield has now been mapped at least by



A. H. Lang

Plate 40C. Rugged topography in the southern part of the Canadian Shield, at Walker Lake, Quebec, north of the mouth of St. Lawrence River.

reconnaissance. Geological interpretations are more difficult than for younger rocks because of the amount of metamorphism and the absence of fossils, which are so useful in correlating strata younger than Precambrian. Great advances have been made in recent years, however, by careful geological studies, aided by geophysical surveys and isotopic age determinations. These determinations indicate the times when metamorphism and orogeny occurred, rather than the times when the rocks were originally formed, but the dates now available show such consistent patterns that considerable confidence is placed in the orogenic and structural interpretations based on them, which are summarized in the following paragraphs and on Figure 13. It is not necessary for every reader to learn this summary but the great potential of the Shield as a source of minerals and the growing complexity of prospecting are strong reasons for advocating familiarity with these main features of present knowledge of the Shield. The following sections should, therefore, be helpful to readers who are reviewing the subject, and might well be gained by beginners during a second reading of this chapter. As the new terms mentioned below have been adopted by the Geological Survey of Canada and are being used fairly widely by other writers, understanding them will assist in the use of maps and reports issued now or in the future.

Interpreting the Canadian Shield

Early geologists regarded the Precambrian rocks of Europe and North America as a 'basement complex' which could not be unravelled in detail because of the metamorphism of the rocks and the absence of fossils to aid in correlations. More ambitious studies of the Canadian Shield were begun more than a century ago, however, and although important contributions to the principles of Precambrian geology were made in other countries, many

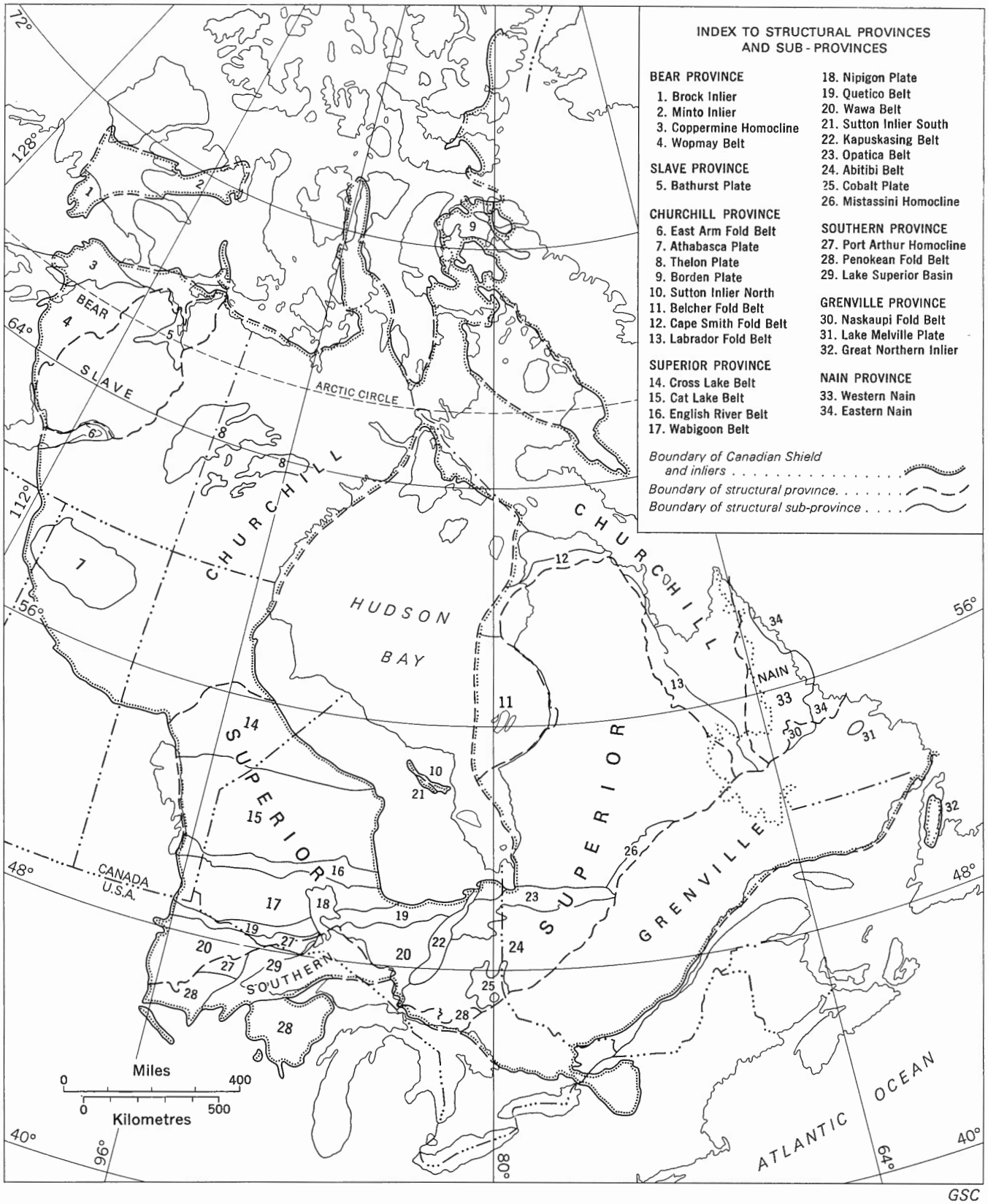

Figure 13. Structural provinces and subprovinces of the Canadian Shield (by C. H. Stockwell).

principles have been established here because the Shield offered such a vast challenge to Canadian geologists.

The first parts of the Shield to be studied were north of Lakes Huron and Superior and near the Ottawa River. After discovery of the Sudbury and Cobalt mining camps about 1900, they were studied in detail. Thus the region from the head of the Great Lakes eastward to Lake Timiskaming came to be regarded as the standard for the whole Shield. This has since been shown to be too sweeping a generalization, so it is now regarded as the classical region of the Shield. One of its features was a group of much-metamorphosed rocks including marble, called the Grenville Series, which many geologists considered the oldest group because of its intense metamorphism. Another feature comprised successions of strongly folded and metamorphosed volcanic and sedimentary strata which were considered Archean; the predominantly volcanic sequences were commonly called the Keewatin Group or Series, and the sedimentary sequences the Timiskaming Group or Series. In places a pronounced unconformity separated these altered volcanic and sedimentary rocks, and plutonic rocks associated with them, from a group of less metamorphosed, more gently folded sediments to which the name Huronian was given. These were considered early Proterozoic. Bodies of younger granite were found intruding these sediments. Flat-lying sediments in Port Arthur region were called the Animikean Series and regarded as late Proterozoic, and still younger, flat, sill-like sheets of diabase were called the Keweenawan and considered latest Proterozoic. In the Cobalt area flat conglomerate was called the Cobalt Series and later was shown to be unfolded equivalents of Huronian strata. Sills and dykes of diabase cutting the Cobalt sediments were considered equivalent to the Keweenawan. A 'front' characterized by igneous metamorphism and granitization was shown by W.H. Collins and others to separate the typical Huronian and typical Grenville rocks. This led M.E. Wilson to call the region containing typical Grenville rocks the 'Grenville subprovince' and the less deformed region to the north and west the 'Superior subprovince'. He regarded the entire Shield as a geological province, but most geologists of today consider it too large to be termed a province. As study of the Shield was extended farther and farther from the classical region, correlations with the first-established sequences became increasingly difficult and it was realized that similar geological conditions probably occurred in different parts of the Shield at different times, which had led to false correlations. Therefore, although some geologists used expressions such as Keewatin-type and Timiskaming-type to allow for uncertainties, the tendency has been to apply new stratigraphical names to each large area as it was investigated. The resulting abundance of names makes the detailed literature on the geology of the Shield more difficult to follow than that for areas containing younger formations whose names can usually be applied over greater distances.

Understanding of the geology of the Canadian Shield has been handicapped by confusion regarding time terms for divisions of the Archean and Proterozoic. Vague terms such as early and late Proterozoic were used because the absence or scarcity of fossils prevented the establishment of eras and periods having the certainty of those agreed on for Paleozoic, Mesozoic, and Tertiary times. Terms like Huronian, Keewatin, and Timiskaming, which designated only certain series of strata in the classical Precambrian area, were applied in a time sense in other, widely separated areas to strata having generally similar appearances and structures, but which might have been formed at different times.

The increasing numbers of isotopic dates becoming avaliable, and the way in which these corroborate structural and lithological evidence, led C.H. Stockwell to propose in 1965 specific time divisions for the Proterozoic. These proposals, which have been adopted by the Geological Survey of Canada, are as follows. The Archean and Proterozoic are called eons, not eras as was done by some writers. The Proterozoic is divided into three eras called Aphebian (the oldest), Helikian, and Hadrynian. The Helikian is divided into an older sub-era called Paleohelikian and a younger one called Neohelikian.

It is now generally agreed that the Shield can and should be divided into main *provinces* but that these should be called structural rather than geological because rocks of similar kinds could have been formed at different times, and because isotopic dating indicates the time of orogeny and metamorphism rather than the time of original formation. The Shield is, accordingly, now divided into the seven provinces outlined on Figure 13. These are named the Superior, Slave, Churchill, Bear, Southern, Nain, and Grenville, and are distinguished mainly by broad differences in internal structural trends and kinds of folding. Boundaries are drawn where one trend is ended by a younger one, either along main unconformities or along 'orogenic fronts', that is, belts bounding the region of influence of an ancient period of mountain building. Isotopic dates fall into patterns that conform with these principal structural differentiations, thus adding to their credibility.

Several geologists have proposed various subprovinces. Stockwell has recently reviewed the subject and indicated preferences where more than one name or boundary was suggested, and he has added others. Some large parts of provinces are, however, still undefined. Most of those that have been adopted are shown on Figure 13 and are mentioned in the following sections. Subprovinces containing folded Archean or Proterozoic strata are called 'fold belts' or 'belts', those containing Archean strata generally being most intensely folded. Subprovinces characterized by strata tilted gently in a single direction are called 'homoclines', and those characterized by flat strata are called 'plates'. Homoclines and plates, most or all of which are Proterozoic, cover older Precambrian rocks.

Stockwell has also defined four principal orogenies in the Shield. Because of uncertainties and degrees of error in isotopic dates, orogenies cannot be dated absolutely. Orogenies are therefore defined by specific rocks in type areas which serve as standards. Orogenies probably occurred at several distinct times in the same parts of the Shield, but the effects of earlier ones were largely oblit-

erated by the most recent deformation. The four orogenies and their general dates in millions of years, based on average isotopic determinations, are the Kenoran (2,490 m.y.) which was the last widespread folding, metamorphism, and plutonic activity in Superior Province; the Hudsonian (1,735 m.y.) for Churchill Province; the Elsonian (1,370 m.y.) for western Nain Province; and the Grenvillian (945 m.y.) for Grenville Province.

Superior Province

Superior Province — the largest of the structural provinces — is characterized by altered volcanic and sedimentary strata and large bodies of granitic rocks and related gneisses. It contains the typical Keewatin volcanics and Timiskaming sediments, and strata that are much like them. Volcanics of various kinds are abundant and commonly are altered to chlorite and other green minerals which give the rocks their popular name *greenstones*. Many greenstone flows contain rounded *pillows* which are evidence that the lava flowed on the bottom of a sea or lake.

Structural trends are mainly easterly. The southeastern part of the province contains the large complex Abitibi Subprovince. This is a wide, folded geosynclinal belt extending between Timmins and Chibougamau, containing volcanic and sedimentary strata, together with anorthosite in the Matagami and Chibougamau areas. The western part of the province contains the Cross Lake, English River, and Quetico fold belts of volcanics and sediments. Unfolded or gently folded cover strata form the Nipigon and Cobalt Plates and the Mistassini Homocline.

Superior Province, particularly Abitibi Subprovince, is one of the largest if not the greatest source of metals in Canada. It is rich in copper, zinc, and gold, and has supplied considerable iron, molybdenum, and other metals. The Cobalt Plate yielded the outstanding silver ores of the Cobalt camp, which is still producing. A study of mines brought into production in Canada from 1956 to 1966 showed that nearly one-third were in Superior Province, that for half of those in Superior Province copper was the main commodity, and that most of the iron, zinc, silver, and gold mines brought into production during that decade were in Superior Province.

Southern Province

The parts of Southern Province in Canadian territory underlie much of Lake Superior and also form the Port Arthur Homocline and the Penokean Fold Belt north of Lake Huron. The province continues southward to underlie parts of Michigan, Wisconsin, and Minnesota, which have yielded much iron ore.

The Penokean Fold Belt contains the classical Huronian strata that include two of the world's leading mining camps: the Sudbury nickel–copper camp and the Elliot Lake uranium camp. A special type of native copper–chalcocite deposit typical of northern Michigan is being mined in the Lake Superior Basin north of Sault Ste. Marie.

Slave Province

Most of the rocks of Slave Province are generally similar to those of Archean age in Superior Province. Although structural trends in these rocks are commonly curved, they strike mainly northerly. The province is mainly underlain by granitic rocks and related gneisses, and by the Yellowknife Group of metamorphosed sedimentary strata and lesser amounts of greenstones. Large gold deposits are mined at Yellowknife, and smaller ones in other parts of the province. It also contains many gold prospects and some prospects carrying beryllium, lithium, and niobium.

Churchill Province

The western part of Churchill Province lies between Superior and Slave Provinces, and is characterized by curving belts of sediments, volcanics, and gneisses. Equivalent rocks underlie part of the Hudson Platform and form part of the Sutton Inlier south of Hudson Bay. They swing northward through the Belcher Islands, and form the Cape Smith and Labrador Fold Belts. Parts of the boundaries between Churchill Province and Superior and Slave Provinces are pronounced unconformities, and other parts are orogenic fronts. In the interior of the province folded rocks are overlain by flat or gently dipping strata that form the Athabasca, Borden, and Thelon Plates.

The northwestern part of Churchill Province, at Great Slave Lake, contains the East Arm Fold Belt of Proterozoic strata, in which occurrences of copper, lead, zinc, uranium, nickel, cobalt, and tungsten have been found. A northerly trending belt in the part of the province lying between Great Slave and Athabasca Lakes, known as the Taltson or Nonacho Belt*, contains several prospects of sulphide minerals and occurrences of uranium. North of Lake Athabasca a belt of older, metamorphosed strata is overlain by Proterozoic sediments and volcanics. Rocks of both groups contain numerous uranium prospects and several past or present producers of uranium. This belt, which is called the Athabasca–Rankin* in some publications, continues in an interrupted way to Hudson Bay where it contains a former nickel mine at Rankin Inlet. Uranium occurrences are unknown in the eastern part of this belt. South of Lake Athabasca a large sheet of flat Proterozoic sandstone and other sediments forms the Athabasca Plate. Between it and Superior Province is a large, complex part of Churchill Province that is one of the principal metal-producing sectors of the Shield. It includes zinc–copper deposits in the Flin Flon and nearby areas, nickel–copper deposits at Thompson and Lynn Lake, and gold mines east of Flin Flon. Eastern parts of the province contain the Quebec–Labrador iron deposits and those of the Belcher Islands, lead–zinc deposits at Richmond Gulf, and deposits of several kinds in the Cape Smith Belt.

Bear Province

An unconformity separates rocks of Slave Province from younger, folded and tilted sediments and volcanics

* These belts are not included in scheme followed on Figure 13.

of Bear Province, a large triangular area between Great Slave and Great Bear Lakes. The older rocks of Bear Province are overlain unconformably by gently dipping, predominantly basaltic strata in the Coppermine Homocline. To the north, rocks related to those of Bear Province form the Brock and Minto inliers which are surrounded by rocks younger than Precambrian and thus are not part of the Shield proper.

Rocks of Bear Province contain the formerly mined Eldorado and Rayrock uranium deposits and a silver–copper deposit being mined at Port Radium. Copper deposits in the Coppermine Homocline are being tested extensively at present because of general improvements in northern transportation, as well as current interest in copper deposits. The deposits, some of which have been known for many years, have some similarity to those of Michigan and north of Sault Ste. Marie. Chalcocite is the chief copper mineral but some amygdaloidal vein and breccia deposits contain native copper, bornite, or chalcopyrite.

Nain Province

Nain Province, lying between the eastern part of Churchill Province and the Labrador Coast, is not yet well mapped geologically. It contains metamorphic rocks resembling some of those of Grenville Province, as well as large bodies of anorthosite. The boundary with Churchill Province appears to be an orogenic front. The province is divided tentatively into western and eastern parts because of differences in isotopic dates. Few mineral deposits have been found so far in either part of Nain Province. Several uranium prospects near Makkovik on the coast of Labrador are close to the tentative position of the Grenville boundary and are considered for the time being to be in Nain Province.

Grenville Province

Grenville Province, which forms the southeastern part of the Shield between Lake Huron and southern Labrador, is separated from southern Superior, eastern Churchill, and Nain Provinces mainly by an orogenic front, called the Grenville Front, which extends northeastward for about 1,000 miles, truncating the trends of the other provinces. Part of the boundary is an unconformity where strata of the Naskaupi Fold Belt rest on rocks of western Nain Province. On the Island of Newfoundland an inlier bounded by faults contains rocks resembling some of those of Grenville Province.

Typical Grenville rocks are crystalline limestone and impure limy rocks, which are particularly common in the southwestern part of the province, and gneisses and schists containing garnet and other minerals typical of high-grade metamorphism of limy and clayey rocks. Also common are stocks and batholiths of salic and mafic plutonic rocks, including anorthosite, and innumerable masses of pegmatite and related rocks. Subprovinces have been proposed for certain parts of Grenville Province but these are not outlined here or on Figure 13 because detailed studies of parts of the province are now in progress, so it seems advisable to await their outcome.

Grenville Province is noted for the occurrence of pegmatitic and metasomatic mineral deposits. These include many metasomatic magnetite deposits, and pegmatites carrying mica, feldspar, apatite, and other minerals, and the special type of uranium deposits of the Bancroft area. Large iron deposits are mined from rocks that are the metamorphosed equivalents of those of the Labrador Belt. Large titanium deposits are mined north of Havre St. Pierre. Veins containing sulphides of zinc and lead have been mined at the New Calumet and Tetreault mines near the southern border of the province, but large, massive or disseminated sulphide deposits have rarely been found.

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PLATFORMS

Interior Platform

The Interior Platform is a large region whose surface is generally called the Interior Plains or the Great Plains. Extending northward from central United States, it forms the mainland of Canada between the Canadian Shield and the Cordillera. As much as 10,000 feet of undisturbed or gently flexed sedimentary strata overlie a basement of Precambrian rocks that slopes gently westward at 15 feet per mile. Much information on the cover rocks and on the position of the basement surface is now available for the southern part of the region, from geophysical surveys and from wells drilled for oil or gas, a considerable number of wells being continued a few feet into Precambrian rocks. Fewer data of these kinds are as yet available for

more northerly parts of the region. The cover strata once extended over part or all of the Shield before being eroded away. Erosion has bevelled the overlapping strata in ways such that the older formations outcrop in relatively narrow belts around much of the perimeter of the Shield, as well-exhibited by the part of the geological map of Canada between Winnipeg and Great Bear Lake. Younger strata extending over larger areas to the west cover the continuations of the Paleozoic and earlier Mesozoic strata so exposed. The Paleozoic strata in central Manitoba are marine beds of limestone, sandstone, and shale of Ordovician, Silurian, and Devonian ages, including beds of salt, anhydrite, and dolomite caused by evaporation in basins partly cut off from the rest of the sea. Farther north the exposed Paleozoic strata are mainly Devonian. The Paleozoic formations are overlain by early Mesozoic strata of marine origin and these in turn by both marine and freshwater Cretaceous formations that form the uppermost strata in much of Saskatchewan and Alberta. At Turtle Mountain in Manitoba and the Cypress Hills in Saskatchewan these beds are overlain by remnants of early Tertiary formations.

The rich soils of the southern part of the platform, particularly in the Manitoba Plain, were derived from the weathering of the underlying strata and the unconsolidated deposits resulting from glaciation. Most of Canada's oil and gas is produced from Paleozoic and Mesozoic strata, mainly in Alberta but also in Saskatchewan, Manitoba, and northeastern British Columbia. The productive beds range from Devonian to Cretaceous in age. Many of the reservoir rocks are limestone reefs containing many openings; other 'stratigraphic' traps such as lenses of porous sandstone and dolomite in non-porous shale or anhydrite are also important. Exploration for oil and gas has recently been extended through most of the plains, including those in the Arctic Archipelago. The Athabasca oil sands, extending for more than 100 miles along the Athabasca River in northern Alberta, are accumulations of heavy oil in sand of Lower Cretaceous age; the total amount of oil is estimated at 100,000 to 300,000 million barrels, more than all other known reserves of the world. Coal is being or has been produced from many places. The Interior Platform also yields potash, salt, gypsum, limestone, and other non-metalliferous products, mining for potash having become a leading industry in Saskatchewan during the last few years. The only large metalliferous deposits known are zinc and lead, in Devonian dolomite immediately south of Great Slave Lake, where a large mining centre has recently been established at Pine Point.

Arctic Platform

The Arctic Platform underlies most of the Arctic Islands lying between the Innuitian Orogen and the exposed part of the Shield. The platform contains flat strata, mainly Ordovician and Silurian limestone, dolomite, and shaly dolomite, but strata of Cambrian, Devonian, and Tertiary ages are also present locally. Some of the strata contain coal. Much interest is now being taken in the possibilities for oil and gas of certain strata.

St. Lawrence Platform

The St. Lawrence Platform flanks the southern part of the Shield from Lake Huron to Quebec City, except for a small area of the Shield called the Frontenac Axis. The surface of the platform southwest of the Axis, is known as the Great Lakes Lowland and that to the northeast as the St. Lawrence Lowland. Both areas are underlain by gently dipping beds of limestone, dolomite, sandstone, and shale of Cambrian, Ordovician, Silurian, Devonian, and Mississippian ages. West of the Axis the beds have a total stratigraphic thickness of 5,877 feet but no one area is known to be underlain by the entire succession of strata because these strata dip gently southwest; the greatest thickness penetrated by drilling is 4,727 feet. East of the Axis, formations in Quebec have a total thickness of at least 10,000 feet. Ordovician and Silurian strata are exposed on Anticosti Island.

The first petroleum field in Canada was in the area north of Lake Erie, which is still producing natural gas and some oil. Most oil was derived from Devonian strata and most gas from Silurian. Important amounts of salt and building materials are produced from St. Lawrence Platform but only a few metalliferous occurrences have been found. The Marmora iron deposit is in Precambrian rocks that were overlapped by a thin covering of Paleozoic strata and so are technically within the Lowlands.

The Monteregian Hills at and near Montreal are the remnants of small alkaline igneous intrusions probably Cretaceous in age, which are more resistant to erosion than the surrounding strata. Mount Royal is a well-known example. Niobium deposits at Oka, Quebec, are believed to be related to Monteregian igneous activity.

Hudson Platform

Hudson Platform underlies most of Hudson Bay and Hudson Bay Lowland between Churchill and Moosonee. The platform is underlain by Ordovician, Silurian, and Devonian strata, largely limestone and dolomite, and by a smaller amount of Jurassic or Cretaceous strata. The thickness of this assemblage of sedimentary rocks is not well known because outcrops are scarce and relatively little drilling has been done. Large deposits of gypsum have been found in the Devonian succession and substantial lignite deposits occur in Mesozoic beds. The region is being investigated as a possible source of oil or gas.

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APPALACHIAN OROGEN

The Appalachian Orogen, which is the northeastern extension of a much longer belt in United States, includes the part of Quebec lying south of the St. Lawrence River and east of a line between Lake Champlain and Quebec City, and all of New Brunswick, Nova Scotia, Prince Edward Island, and the Island of Newfoundland. The region is characterized by northeasterly trending geological structures formed during Paleozoic times, in contrast to the younger orogenies of the Cordillera. The topography of the Appalachians generally reflects these structural trends because a tilted, ancient plateau surface sloping southeast has been carved into hills and valleys by stream and wave erosion. In the interior of Gaspé, elevations rise to more than 4,200 feet above sea level to form the Shickshock Mountains.

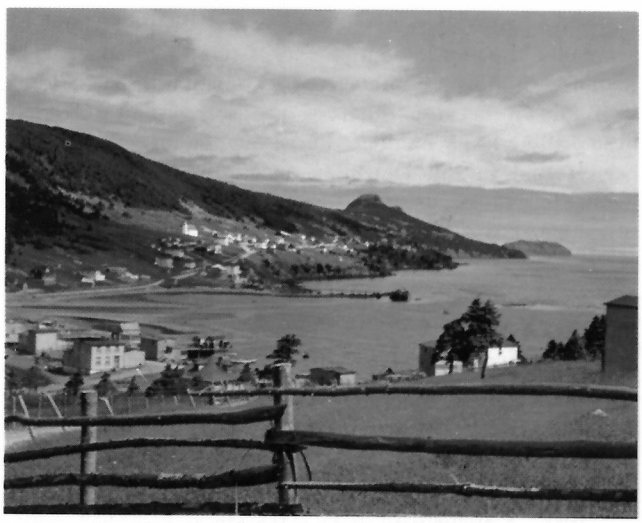
The boundary between the much-disturbed Paleozoic strata in the Appalachian Orogen and the flat-lying Paleozoic beds of the St. Lawrence Platform is a great fault extending in the form of an arc northeastward from Lake Champlain. This fault is responsible for the sweeping curve of the south shore of the lower St. Lawrence. The faulting seems to have resulted mainly from thrusts that occurred during the Ordovician and Devonian periods, but there may also have been movement at other times.

Precambrian rocks of Helikian or earlier age exposed in an inlier in the western part of the Island of Newfoundland resemble those of Grenville Province but are separated from the Canadian Shield proper by Paleozoic strata. The remainder of the region is the northern part of the Appalachian Orogen. This was developed mainly in late Hadrynian to Permian times, when great thicknesses of sediments were laid down. These included evaporite sediments in the Mississipian and continental iron-bearing 'red beds' in the Triassic. In much of the orogen, deposition took place in different troughs and local basins, strata of the same ages varying greatly in kinds of rock and in their contained fossils. Salic and mafic volcanics were deposited at various times. The greatest thickness of Middle Silurian strata in North America is exposed near Chaleur Bay, where it comprises 8,427 feet of sediments and 4,626 feet of volcanics.



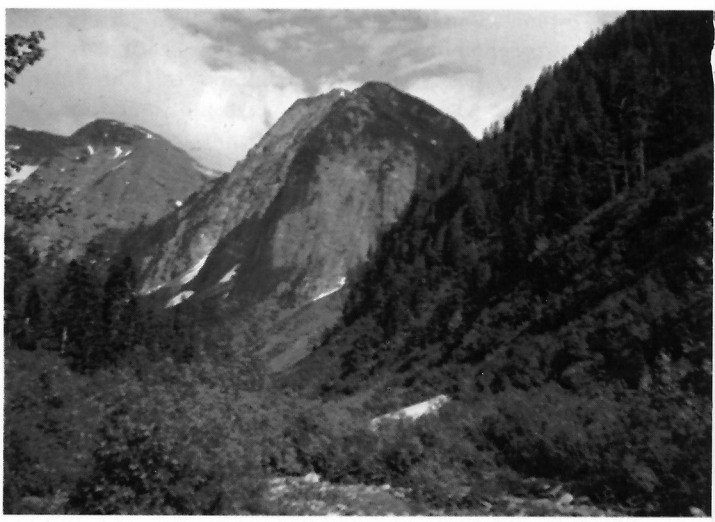
D. M. Baird

Plate 42A. Jagged mountains formed from sedimentary strata, Peyto Lake, Banff National Park, Alberta.



D. M. Baird

Plate 41. Chapel Arm in eastern Newfoundland showing a long, northeast-trending bay with points on each side.



S. Duffell

Plate 42B. View in Coast Mountains near Terrace, B.C., illustrating the rounded erosion forms typical of plutonic rocks.

Orogenies at different times folded the strata that had been deposited, and caused metamorphism, development of plutonic rocks, and mineralization. The main orogenies were the Taconic during the Ordovician period, and the Acadian during the Devonian period. Parts of the region were deformed again by folding and faulting at the close of the Carboniferous period during an orogeny that was more pronounced in the United States Appalachian. Numerous bodies of granite and related igneous rocks were formed during the Acadian orogeny in Lower, Middle, and Upper Devonian times. Many bodies of ultramafic rocks occur intermittently in northeasterly trending belts in the Eastern Townships and in Newfoundland. Most of these intrude Cambrian and Ordovician strata and are probably related to the Taconic orogeny.

The Appalachian Orogen now yields about 9 per cent of the Canadian production of minerals, including fuels. Important industrial minerals are asbestos associated with basic rocks in the Eastern Townships, and gypsum, barite, and salt produced from Mississippian strata in Nova Scotia. Some gypsum is also mined in New Brunswick. From veins in granite and related rocks in Newfoundland comes most of Canada's production of fluorite. Pennsylvania strata contain the coal deposits of Nova Scotia. Copper, zinc, lead, gold, and silver are produced, mainly from central Gaspé and central Newfoundland. Most of the deposits are related to the Acadian orogeny, as were numerous gold-bearing veins formerly mined in Nova Scotia. Stratiform iron deposits in Ordovician sediments at Wabana, Newfoundland, were mined for many years, until recently.

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CORDILLERAN OROGEN

The Canadian Cordillera is part of a wide belt of high mountains and plateaux extending along the western sides of South and North America and continuing through the Aleutian Islands and along the coast of Asia. The North American Cordillera is divided into four main segments by crosscutting structures, the most northerly segment including all of Canada and Alaska. The part of this segment that lies in British Columbia and Alberta is clearly divided into two main geological and structural provinces by an extraordinarily long, straight valley called the Rocky Mountain Trench. It extends from the United States boundary almost to the boundary between British Columbia and Yukon Territory, nearly 1,000 miles, and results from erosion along a zone of faults. The region between the Trench and the Pacific is underlain mainly by plutonic, volcanic, and metamorphic rocks. East of the Trench the Rocky Mountains and the Foothills Belt are formed almost entirely of sedimentary strata cast into great folds and fault blocks. The Trench loses its identity at about latitude 60 degrees, near the place where the Rocky Mountains peter out. The geology of the parts of the Yukon and Northwest Territories lying northwest of the Rocky Mountains is generally similar to that of the Western Cordillera of British Columbia and is considered to be its equivalent. Farther east in Northwest Territories the Mackenzie Mountains west of Mackenzie River have general geological similarities with the Rocky Mountains, and the Franklin Mountains east of Mackenzie River have some correspondence with the Foothills of the Rockies. The boundary between the Western and Eastern Cordilleras is, accordingly, considered to swing in a great arc from latitude 60 degrees along the western limits of the Mackenzie Mountains and then to swing westward across Yukon Territory in such a way that the Richardson and British Mountains south of the Arctic coast are parts of the Eastern Cordillera.

The Western Cordillera is mainly a source of metals but also yields valuable amounts of industrial minerals and coal. The Eastern Cordillera is noted chiefly for coal, petroleum, and industrial minerals.

Western Cordillera

The western part of the Cordilleran Orogen is the site of a series of geosynclines of a kind in which volcanic and plutonic rocks as well as sediments are formed. The strata that accumulated in them were folded and faulted during orogenies occurring at different times, but mainly during the late Jurassic and Cretaceous periods. Many of the metalliferous deposits of the region were formed at these times, but others may have been associated with earlier orogenies. Three areas of much metamorphosed and granitized rocks in the interior of British Columbia and Yukon Territory form the Shuswap, Wolverine, and Yukon metamorphic complexes. Although some of the rocks in them may be metamorphosed equivalents of Proterozoic strata occurring in southeastern British Columbia, others are altered Paleozoic rocks and some may be still younger. A prominent feature west of these complexes is the large Coast Plutonic Complex which was formerly called the Coast Range Batholith but is now known to be too large and diversified to be so termed. Large and small plutons lying between it and the Eastern Cordillera are interspersed partly by the metamorphic complexes and partly by areas underlain by volcanics and sediments of Paleozoic and Mesozoic ages. After the main periods of orogeny and erosion, large sheets of basaltic lava covered older rocks in much of the interior of British Columbia during the early Tertiary, when sediments were also laid down in local basins. These volcanic and sedimentary sheets are younger than most mineralization in the region, and probably hide mineral deposits in the older rocks on which they rest.

Ancient mountains formed during the late Mesozoic

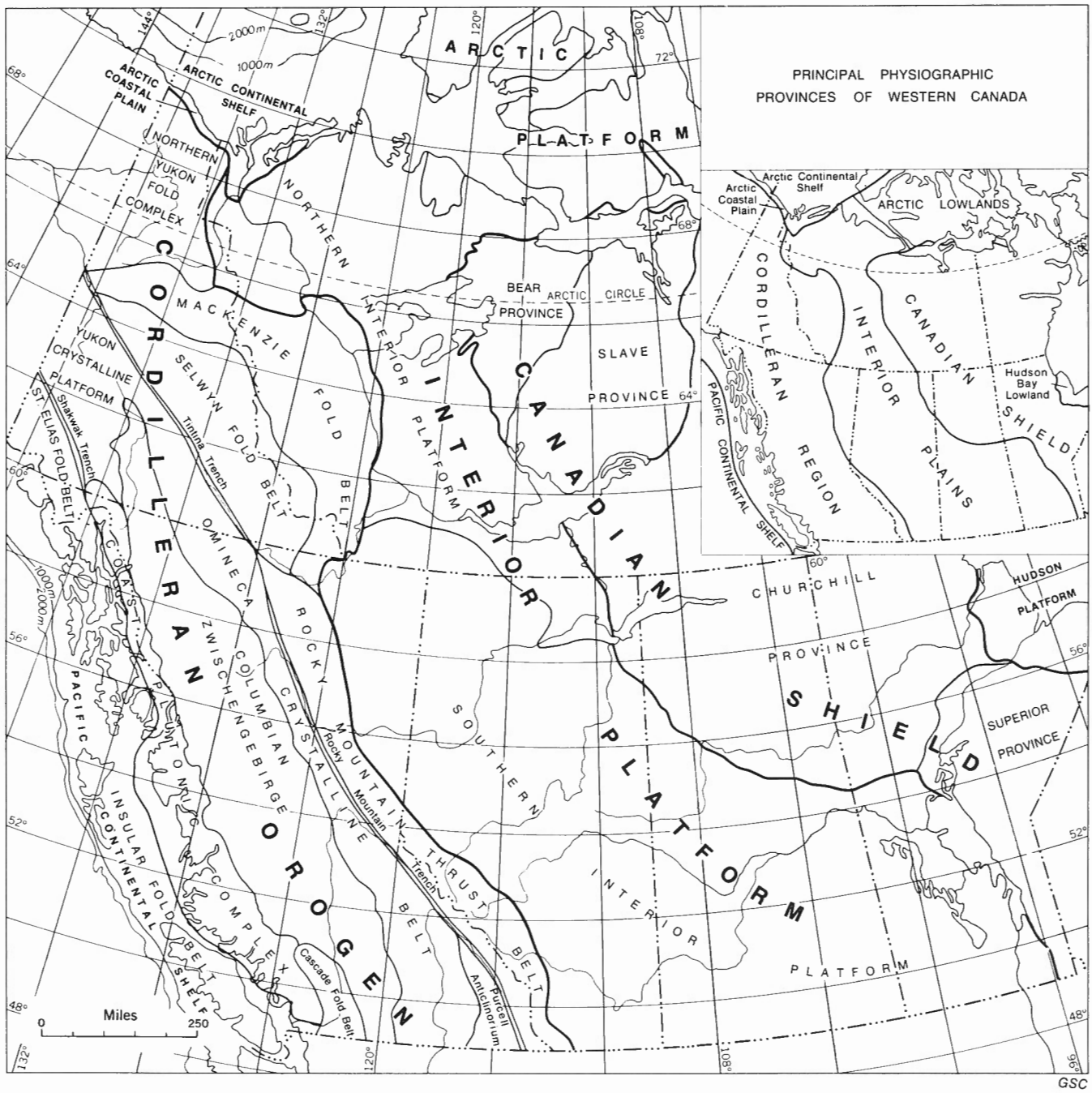

Figure 14. Main geological elements of western Canada.

orogenies were worn to a rolling land surface that was uplifted in early Tertiary time. This uplifting increased the erosional power of streams that cut deep valleys into the old surface, remnants of which are apparent in the tops of mountains with summits of fairly even elevations, and in large, rolling plateaux interrupted by deep, linear valleys that are commonly related to erosion along faults. In many places the tops of plateaux have uniformly flat surfaces caused by the Tertiary lava flows mentioned above. Some of these surfaces extend for miles, and others are dissected into mesas and buttes.

The Western Cordillera, which was Canada's leading source of metals until the Canadian Shield took the lead early in the present century, is still a large producer, and has great potential. Large deposits of lead, zinc, and silver are mined in southeastern British Columbia. Massive and porphyry–copper types of copper deposits are or have been mined in several areas. A large molybdenum deposit recently began to produce in central British Columbia. Many placer and lode deposits were mined for gold, and some are still operated. The coastal region contains many metasomatic magnetite deposits, some of which yield cop-

per as well as iron. Asbestos deposits are mined in northern British Columbia and in the Yukon. Deposits of other industrial minerals are worked in various parts of British Columbia.

Eastern Cordillera

The mountains and foothills of the Eastern Cordillera were carved by the erosion of great thicknesses of sediments that were deposited in geosynclines. Thousands of feet of sediments were laid down from late Proterozoic to Cretaceous and, in places, early Tertiary times. These sediments became the interbedded limestone, dolomite, argillite, shale, sandstone, quartzite, and conglomerate that were deformed by orogenies at various times from Hadrynian to Tertiary. Most of the structures now readily observable are those of the great Laramide Orogeny of early Tertiary age. The sediments were later sculptured into the saw-tooth shapes characteristic of the Rocky Mountains and the more rounded shapes of the more northerly ranges. Closely spaced thrust faults divide the sediments forming the Rockies and southern Foothills into a series of fault-blocks. The central and northern Foothills are much folded but faults are less common. The Mackenzie and Franklin Mountains are formed mainly of Paleozoic sediments cast into broad, simple folds interspersed by complex folds and faults. Various structures and trends, developed at different times, occur in the Richardson and British Mountains.

The principal mineral resources of the Eastern Cordillera have been fuels. Petroleum is obtained mainly from Mississippian strata in the Turner Valley oil-field in the Foothills south of Calgary, and from Devonian strata at Norman Wells in a plain between the Mackenzie and Franklin Mountains. Natural gas is produced in the Foothills. The more severely folded and faulted parts of the Cordillera are not favourable for retention of any oil or gas that may once have been present. Coal has been mined at many places in the Rocky Mountains and Foothills, and is continuing chiefly in the Crowsnest Pass area. Most coal seams are in Cretaceous strata.

Few metalliferous deposits have been found in the Eastern Cordillera, compared with the great number found to their west. Zinc, lead, and silver have been mined from the Monarch and Kicking Horse strata-bound deposits in Cambrian dolomite, near Field in the Rocky Mountains. Veins containing zinc, lead, gold, and silver have been mined in an area east of the southern part of the Rocky Mountain Trench, but the geology of this area is not typical of that of most of the Rocky Mountains. A stratiform copper deposit has been discovered in sediments of Hadrynian age in Mackenzie Mountains. A large deposit of iron-formation of Hadrynian age was found recently at Snake River in the Mackenzie Mountains by geologists mapping for an oil company.

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INNUITIAN OROGEN

Extending across much of the Queen Elizabeth Islands and northernmost Greenland is the Innuitian Orogen, the topography of which is characterized by low plateaux, mountains, and ridges rising as high as 10,000 feet. The region extends northeasterly from Prince Patrick Island and includes all of Axel Heiberg Island and much of Ellesmere Island. In places it is more than 200 miles wide. It is underlain by moderately to intensely folded rocks ranging in age from probable Proterozoic to Cretaceous and Tertiary. The strata are mainly sedimentary but include some metamorphic and volcanic rocks.

Five separate fold belts trending in different directions have been recognized and named. In some the strata were folded before the Silurian period, in others the strata were folded in the Silurian and Devonian, the late Paleozoic, and in the late Cretaceous and early Tertiary. Granitic rocks have been found in the northern part of the region. Some belts appear to be potentially favourable for occurrences of mineral fuels, and others for metalliferous or non-metalliferous deposits. Coal has been found at several places, in strata of different ages. The thickest seams known are in beds of apparently Tertiary age on Ellesmere and Axel Heiberg Islands. The less deformed parts of the Innuitian Orogen offer possibilities for oil and gas, which are being investigated by several companies. Lead and zinc have been reported from Little Cornwallis Island, and magnetite from Axel Heiberg Island. Gypsum occurs at various places, in strata deposited during several Paleozoic periods.

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CONTINENTAL SHELVES

The presence of continental shelves extending off the Pacific and Atlantic coasts, and their approximate limits, have long been known because of soundings. More recently, shelves have been shown to extend between the Arctic Islands and to their northwest, and along the coast of Baffin Island. The shelves are bounded by fairly abrupt slopes, which in the Atlantic begin at depths of 100 to 200 fathoms. These slopes, not the present shorelines, were adopted as the continental boundaries by a recent international convention at Geneva.

Increased attention has been paid to the possibility of finding deposits of petroleum or natural gas in rocks underlying parts of the continental shelves, and of finding mineral deposits beneath other parts. Also, certain kinds of mineral deposits are known to be forming on the surface of some parts of the shelves. Geological knowledge of the rocks underlying the continental shelves is much more limited than is that for land areas because of difficulties of observation, but considerable information is now being obtained from geophysical surveys of various kinds, from boreholes, and from dredging and diving. These studies show that conditions more or less similar to those on nearby mainlands are present in several places beneath the shelves and, locally, extensions of faults and other structures have been traced or indicated. The Pacific Coast is characterized by fiords where glaciers gouged previously existing valleys; the offshore extensions of some of these fiords are being studied.

EFFECTS OF GLACIATION

Glaciers that covered most of Canada during the Pleistocene period greatly affected the land surface by removing residual soil, by planing and gouging rock surfaces through abrasion of rocks frozen in the base of slowly moving ice, and by depositing gravel, sand, clays, and other glacial deposits either directly or in streams and lakes formed from the melting ice. Earlier knowledge of these conditions, based on studies of the directions of ice movement and the successions of glacial overburden in various regions, have recently been supplemented by radiocarbon dating of organic materials in the younger Pleistocene deposits. This combined evidence indicates that the Pleistocene began about 1,500,000 years ago, that there were four main stages of glaciation each lasting about 100,000 years and separated by interglacial stages (which may have been longer than the glacial stages) during which the climate, at times, was warmer than it is today. The glacial period in general is considered to have ended about 10,000 years ago, but this date is not definite, because the ice melted at different times in different parts of the country, and in some places in the Arctic and in high parts of the Cordillera glacial conditions remain today. Most of the glacial effects to be seen now are those of the last stage. Part of western Yukon Territory was not glaciated because the highest mountains in Canada, the St. Elias Mountains, lying to the west, prevented the moisture-laden clouds from the Pacific from reaching this area, and thus ice did not form despite the coldness of the period. Some parts of the Arctic Islands were unglaciated or affected only moderately. The lack of glaciation in part of the Yukon was responsible for the preservation and the relatively easy discovery and mining of the unusually rich gold placers of the Klondike area.

The total amount of bedrock removed by abrasion was relatively small, but, particularly in the Cordillera, valley glaciers modified the topography greatly by changing the shape of valleys formed during Tertiary times to the U-shapes characteristic of valley glaciation. The main effects of continental glaciation were the removal of much residual soil that must have been deposited during the Tertiary, and the laying down of unconsolidated deposits varying in thickness from a few inches to more than 1,000 feet. Some of these deposits, called moraines, were formed from sand, gravel, and boulders pushed in front of a glacier or along its sides (*see* Pl. 10A). Others were formed of stratified sand or clay deposited in streams or lakes containing water melted from waning glaciers.

Changes in sea levels occurred during and after the Pleistocene period. In the primary stage, the removal of water from the oceans to form ice and the resultant huge weight of several thousand feet of ice spread over many thousands of square miles, caused some relative sinking of the continent. When the ice melted after the Pleistocene period, the land began to rise slowly, as is evidenced by the raised beaches and terraces along coast lines and on the shores of the Great Lakes and Arctic Islands.

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6 obtaining instruction

The need for organized instruction in prospecting has been recognized in Canada for many years, with the result that good courses of various kinds are available in several parts of the country. Some persons who had attended one or other of these courses later made important discoveries. Facilities of this kind will probably be increased from time to time, both in technical schools and in various provisions for adult education. The kinds of facilities now available are outlined below, and several of the courses are described briefly. These courses are strongly recommended for anyone intending to prospect on his own or to seek employment in some form of prospecting without acquiring full university training in one of the specialties related to this subject. The information in this chapter is intended as a general guide only and should be supplemented by obtaining other data on particular courses, because they vary from year to year, new ones are added from time to time, all organizations could not be canvassed for information during the preparation of this book, and the descriptions of some courses are more detailed than is desirable here.

Those who do not attend classes or take correspondence courses can, however, greatly increase their proficiency by independent study; therefore suggestions are included for supplementing the introductory information contained in this book.

LONG COURSES

Certain high schools and technical schools give courses in elementary geology or mineralogy, some offering evening classes, but none of these usually include specific instruction in prospecting. Technical courses intermediate between high school and university education, whose numbers and types vary from time to time, are available from several organizations. Some of those available at the time of writing are outlined below.

At least three organizations in Ontario supply training in related subjects that is shorter than a full university course. The Provincial Institute of Mining at Haileybury provides two- and three-year courses in mining and related subjects for students who have Ontario Grade XII standing or its equivalent in english, history, mathematics, and science. Lakehead University at Thunder Bay gives the first year of degree courses in geology and mining engineering, and a special course in surveying, mapping, surface prospecting, and geology. Cambrian College at Sault Ste. Marie offers a two-year course for geological technicians, including such subjects as geology, mineralogy, economic geology, geophysics, geochemistry, surveying, and drafting.

The Northern Alberta Institute of Technology at Edmonton offers a two-year course including geology, mineralogy, drafting, and other subjects.

The College of Trades and Technology, St. John's, Newfoundland, provides a course in mineral and rock identification, geology, and practical geochemistry and geophysics.

The British Columbia Institute of Technology, 3700 Willingdon Ave., Burnaby 2, offers courses in geology, mining, chemistry, geophysical prospecting, and surveying.

SHORT COURSES

Classes for prospectors and others who are interested in a general way are held annually in several provinces and in the Northwest Territories and the Yukon. The importance and popularity of this means of instruction are proven by the attendance, year after year, of many of the same persons. The details of the courses vary from province to province and from year to year, but they are usually held for a few weeks during the winter; some are held in the evenings only, and others include afternoon and evening classes; they are usually free. In some provinces the classes are held only in one city, and in others they are held at several centres. The instruction usually consists of lectures on geology, prospecting methods, and several related topics, as well as training in the identification of principal minerals and rocks by actually working with specimens supplied for the purpose. Anyone who intends to take up prospecting would be well advised to attend one of these courses, even if it were necessary to take leave and travel to the nearest place where a course is held. The following provides brief information on courses recently available.

Alberta

Classes are held in Edmonton during the winter under joint auspices of the University of Alberta, the Alberta and Northwest Chamber of Mines and Resources, 10060 - 100th Street, Edmonton, and the Edmonton Branch of the Canadian Institute of Mining and Metallurgy.

British Columbia

Classes are held in Vancouver under the auspices of the British Columbia and Yukon Chamber of Mines with the co-operation of the Adult Education Department of the Vancouver School Board, the University of British Columbia, and the B.C. Department of Mines and Petroleum Resources. Courses were begun in 1918, since when some 7,000 persons have been enrolled. In recent years classes have been held two evenings weekly for three and a half months beginning in October. Instruction is given in mineralogy, geology, mining, and prospecting techniques. The

B.C. Department of Mines and Petroleum Resources also gives courses at certain other centres if requested.

Manitoba

The Evening Institute of the University of Manitoba gives courses in Winnipeg on subjects related to prospecting.

Nova Scotia

The Mining Society of Nova Scotia and the Nova Scotia Department of Mines sponsor a course for prospectors given at two centres in the province. It consists of eleven lectures and laboratory periods spread over nearly six weeks.

Ontario

Courses in prospecting have been held in Ontario since late in the last century. Courses sponsored in whole or in part by the Ontario Department of Mines have been given recently at Thunder Bay, Manitouwadge, and Toronto. Those held in Toronto were sponsored jointly by the Ontario Department of Mines and the Prospectors and Developers Association, and included a preliminary and a more advanced course. One-week courses have been given recently in northwestern Ontario, arranged jointly by the Ontario Department of Mines and the federal Department of Indian Affairs and Northern Development. The Ontario Department of Mines recently added a short field course in mineral exploration to its program.

Quebec

Classes for beginners and more experienced prospectors are held at several centres by the Quebec Department of Natural Resources. The lectures are given either in French or English depending on the mother tongue of the majority of those attending. This department also sponsors two longer courses in prospecting conducted for about 4 or 5 weeks (150 hours) each spring at Laval University in Quebec City and at Ecole Polytechnique of the University of Montreal. The latter course includes instruction in mineralogy, geology, mining laws, and prospecting methods; instruction is given in English as well as French during laboratory periods. A seven-week course has also been given recently at Ecole Polytechnique to provide instruction for technicians on advanced prospecting projects.

Saskatchewan

The Department of Mineral Resources recently held a Prospector's School at La Ronge for about three weeks, and also gave one week of instruction at Prince Albert Penitentiary.

Yukon Territory

A course sponsored by the Yukon Chamber of Mines is conducted annually at Whitehorse. In recent years instruction was given by the Resident Geologist of the Geological Survey of Canada and others, on introductory geology and the fundamentals of prospecting. A shorter course was given at Mayo in 1968 by the Resident Geologist.

CORRESPONDENCE COURSES

The British Columbia Department of Education offers a good correspondence course in geology and prospecting for students, including adults, having Grade X standing. The course is open to eligible persons of other provinces except when difficulties exist that would limit the effectiveness of the instruction. The course is conducted through a series of twenty easily understood, well-illustrated papers including tests to be returned for grading. It is not a revision of a course in geology given previously, but an entirely new one prepared in 1964. Inquiries should be addressed to: Director, Secondary School Correspondence Division, 546 Michigan St., Victoria, B.C.

The Welfare Services Branch of the Department of Veterans Affairs, Ottawa, offers a correspondence course in prospecting, using booklets titled "Geology and Mineralogy", "Prospecting", "Practical Mining", and "Business of Prospecting and Mining". These were prepared for the Canadian Legion Educational Services, with the help of the Geological Survey of Canada. The course is open to veterans of the Canadian armed forces, federal civil servants, and inmates of penitentiaries.

INDEPENDENT STUDY

Those who attend classes in prospecting should be prepared to study independently as well. Those who do not attend classes or take correspondence courses can do much to educate themselves. Naturally, persons differ in their capacity and inclination for study, and there have been good prospectors who had little 'book learning', but they would be the first to agree that study is most desirable so long as it is combined with practical experience, common sense, and willingness to work. Hopefully, the present book will serve as a useful introduction to the subject, but it cannot possibly cover all that a competent prospector should know. The following procedure is suggested as a practical way of gaining additional knowledge by studying at home or in libraries.

(1) Study the regulations covering staking and related matters for the province concerned. Copies of regulations can be obtained from Mining Recording offices and from the head office of the provincial department of mines or its equivalent. For several provinces, these regulations are explained in condensed, easily understood pamphlets as well as in the official 'acts'.

(2) Become familiar with the services of provincial and federal departments for supplying publications, identifying mineral specimens, and assaying samples. It would be impossible for these departments to identify or assay every mineral or rock a beginner encounters, but they can be of great assistance when an occurrence of possible significance has been found. Much unnecessary delay in receiving replies is caused by sending letters, specimens, or samples to the wrong government agency, by requesting work of a kind that no government agency undertakes, and by addressing letters and packages vaguely; therefore, knowledge of these

matters is an important qualification for competent prospectors (*see* Chapters 8 and 17). Letters and packages should always be addressed impersonally to an organization, not to a member who may have written a report or whom the prospector may have met, because the matter may not be within his duties, or he may be absent, or no longer on the staff. For example, the writer has had letters asking for a copy of a report, or map, or other publication re-addressed to him in the field, and has had to send them back to headquarters, where the request could have been handled within a day if addressed merely "Geological Survey of Canada, Ottawa, Ontario".

(3) Obtain one of the recommended elementary books on mineralogy, and a set of common minerals and rocks, and make a determined effort to become proficient in their identification.

(4) Read some of the other recommended publications. A good way to begin would be with one of the books on elementary geology and with "Geology and Economic Minerals of Canada". Also, many references for additional reading are listed in this book. Many of the items listed are articles that are out of print or that appeared in technical journals, and are available only in libraries.

(5) Subscribe to at least one of the mining newspapers or magazines. They contain articles dealing specifically with prospecting from time to time, and also serve to keep a prospector posted on minerals in demand, prices of metals and minerals, and areas where prospecting and mining are active.

(6) If a prospector decides to concentrate on a particular metal or mineral, even for a short time, he should study at least one publication on that metal or mineral, if one is available. More recent publications might be obtained by writing to the federal or appropriate provincial mining department.

(7) If prospecting is to be confined to the home region, or if other fields are being considered, obtain and study appropriate geological maps and reports, or consult them in a library.

A prospector will benefit by attending meetings such as those of the Prospectors and Developers Association, at which papers and courses on many topics related to prospecting are presented.

TRAINING IN THE FIELD

Many features of prospecting can be mastered only by actual experience in the field. No amount of reading can take the place of practical experience; the two supplement one another and each is important. Good ways for a beginner to get experience quickly are to spend at least one season working for a company that employs and trains unskilled prospectors, or to form a private partnership with an experienced prospector. In these ways experience can be gained not only in the technical aspects of prospecting, but also in the equally important matters of travelling and living in unsettled areas.

Several companies engage prospectors. Some merely finance prospectors who work alone or in two-man teams, who work more or less where and how they like, and it is sometimes possible for a beginner to be assigned to work with an experienced man who can teach him as the season progresses. Other companies having a large concession or group of claims to prospect, or interested in prospecting a large unstaked area, organize parties to undertake systematic prospecting, surveying, geological mapping, or geophysical or geochemical prospecting. These parties are led by scientists or engineers, and they may include both experienced prospectors and students or local labourers who receive training. Persons seeking such employment can learn of companies that do work of this kind by reading mining newspapers, and can then apply directly to the companies. Also, they might obtain such a job through the Canada Manpower Centres or other employment services.

Alternatively, one can gain field experience independently by intelligent observation of rocks and minerals as they occur in the home region or in the region to which one travels. It is most important to become familiar with rocks and minerals in place, not merely by studying specimens, because such features as structures and weathering are best observed in actual outcrops. It is also very important to learn what mineral deposits actually look like, how they are explored, and what size of deposit is likely to be worth further investigation. An idea of these matters can be gained by visiting abandoned prospects, whose locations can be learned from geological maps or reports, and by visiting prospects that are being explored. Producing mines are not usually open to visitors, but the owners of properties in earlier stages often permit prospectors to examine the showings. In 1969 the Ontario Department of Mines issued a list of producing mines in that province that provide tours for the public, at least of surface installations.

Supervision of prospectors in the field has been undertaken to some extent by the British Columbia Department of Mines, the Saskatchewan Department of Mineral Resources, and the administration of the Northwest and Yukon Territories (*see* Appendix VII). In addition to these organized training schemes, chiefs of geological survey parties and other officials of the federal and provincial governments have helped, incidentally to their regular duties, to improve the skill of prospectors encountered in the field.



7 equipment and travel

Equipment, provisions, transportation, woodcraft, etc., are vital considerations for prospectors. These topics cannot be discussed fully in a publication of this kind because of the varied requirements for different regions and for different types of prospecting, and because much depends on individual preference and finances. A prospector must have at least a minimum of tools, such as a pick and an axe, and certain other items are almost indispensable. If he is prospecting near his home he may not need to travel far or to camp, and in the more settled parts of the country it is sometimes possible for prospectors to find lodging, but in general a prospector needs equipment for travelling and camping, and must know how to use it; the desirability of thorough preparation for all but the shortest trips cannot be too strongly emphasized. All that is attempted here is to provide basic information on equipment and problems of travel for beginners and for more experienced persons unfamiliar with certain regions or kinds of equipment. Beginners will find additional useful information on the subjects and related matters in handbooks on camping, woodcraft, or hunting. The information in this chapter refers only to normal 'bush' prospecting; special clothing and equipment required for work in the Arctic and in remote, high mountainous regions and such items as tractor-drawn living quarters are not discussed because this chapter is intended mainly to discuss the needs of normal, conventional prospecting.

A few general remarks will apply to all types of equipment. There is a happy medium in respect to both quality and quantity. In general, the cheaper articles do not stand up to the kind of usage they have to receive, yet very expensive articles are not necessary; good average quality is usually most satisfactory. In deciding on the amount to be taken, the aim should be to assure an amount adequate for reasonably comfortable living (which is closely connected with working efficiency) but to avoid being burdened with unnecessary gear either during the day's work or when moving camp. Another consideration is that although some articles can be bought more cheaply in cities, many articles that have stood the test of time for use in a particular region can best be bought at stores in the smaller towns from which one sets out on a trip. All essential articles of clothing, groceries, utensils, and ordinary tools such as picks, shovels, and axes can be bought in this way, and canoes are often available. If the cost of bringing in equipment is considered, the higher prices charged in outlying places may be negligible, particularly in view of the advice that can be obtained from local persons. When planning a trip, it might be advisable to write to a merchant at the take-off point, for information on items available and their prices. If the name of such a merchant is not known, the request might be enclosed in a letter to the local postmaster, asking him to forward it to a suitable person.

Most prospectors cannot afford to engage local outfitters or guides, but when this is possible it would be a good way for a beginner, or anyone unfamiliar with the particular mode of travel to be used, to acquire experience.

Government agencies are not permitted to recommend firms or dealers; no names and addresses of suppliers are therefore listed here. Information of this kind can be obtained from advertisements in mining papers and magazines, or from a telephone directory under such headings as sporting goods, camp equipment, hardware, mining supplies, laboratory equipment, and scientific equipment.

CLOTHING AND GENERAL EQUIPMENT

It is not essential to have much special clothing or general equipment. Any outdoor worker or man who engages in outdoor sports would have nearly everything required. Town clothes are not suitable, although apart from footwear, they will serve; if possible, however, it is much better to have proper outdoor clothing, of which a wide selection is available. The following list is not meant to include all the ordinary items needed, but to give advice on certain matters that may be important for beginners or persons unfamiliar with some items.

Footwear

The importance of proper socks and boots cannot be overemphasized. Socks should be woollen, of medium or heavy weight, and they must fit well. Under some conditions it is advisable to carry a spare pair of socks during the day in case of need. Three to six pairs should be taken on any but the shortest trip.

There are many kinds of boots, each of which has advantages for certain conditions, and much depends on individual preference. The main points are not to wear low shoes because of the danger of turning an ankle; to have soles sufficiently thick to protect the foot when walking on rough rocks; and to have the boot fit snugly enough at the heel to prevent the heel from moving in the boot; elsewhere there should be plenty of room for the foot to expand, as it does when doing much walking, particularly when carrying a load. High-topped boots were popular several years ago, but most woodsmen now wear boots that come just above the ankle, 5 to 8 inches high. Higher boots may be desirable in a few areas in southern British Columbia and Alberta where rattlesnakes occur, and in parts of the Canadian Shield where there is much 'buck-

brush' or 'Labrador tea' (dense shrubs about knee height that are hard on clothing and shins). In most parts of the Shield the favourite boots are strong, but not too heavy, leather boots reaching just above the ankle and having neoprene soles; or boots 8 inches or more in height having rubber bottoms extending to the ankle, with leather uppers cemented and stitched to the rubber; the latter are uncomfortable in very warm weather. Some brands of this type are made of leather that is unnecessarily stiff and heavy, causing chafing of the heel or ankle, but the better ones, sometimes called hunting shoes, have soft, light-leather uppers. Boots of the last-named type require thick felt insoles, a spare pair being desirable to permit drying, as they absorb perspiration. Crepe-rubber soles wear out quickly on rock, but are otherwise fairly suitable. Leather soles are too slippery unless hob-nails are added, but nails are undesirable where canoes or aircraft floats are concerned. Neoprene soles are suitable for most parts of the Shield and many other regions but nailed leather soles are desirable in mountains. In hilly or mountainous country it is important to have boots with strong counters along the sides of the heel, to prevent the boots from getting out of shape when used on hillsides. Boots with moccasin-type stitching at the toes wear out quickly in brushy regions. In general, a pair of good boots will last a season in the Shield, but it is desirable to have two pairs so that one pair can be left in camp to dry. If two pairs are taken, it is often desirable to have one pair of leather and the other of the hunting-shoe type. In the mountains, two pairs of good leather boots may be worn out in a season if much time is spent in rock climbing or on talus slopes.

Boots should not be dried too close to a stove or fire, as they may be damaged or burnt. To speed the drying of the insides, warmed pebbles may be poured into them. After drying, the leather should be rubbed with dubbin or other water-proof grease or oil; as salt damages leather, greases containing it, such as butter or bacon grease, should not be used. Light footwear is desirable for wearing in camp and on long canoe trips. For these purposes some woodsmen prefer Indian moccasins obtained locally, and wear special 'moccasin' rubbers with them when necessary; others dislike moccasins because they lack a raised heel.

Underwear

Two suits of two-piece wool or wool mixture underwear are considered essential for a trip of more than a few days. In most parts of Canada it is cold at times even in summer, therefore, woollen underwear is desirable, not only for its warmth but because it absorbs perspiration.

Trousers

In summer most woodsmen wear ordinary khaki or blue denim trousers, but in very rainy or brushy regions some use canvas ones.

Coats

Some sort of water-repellant and wind-resistant coat is essential; this should not be made of rubber, plastic, or oilskin because these materials do not permit perspiration to escape when walking or working. A light windbreaker or parka that can be carried when not needed is good for warm weather, but a heavier, canvas hunting coat or 'bone dry' is better during cool or very wet weather. It may be desirable to have both a windbreaker and a parka or a canvas hunting coat.

Under some conditions it is also desirable to have a slicker or two-piece rain suit to use during heavy rain in camp, or when in a canoe or boat, or on a horse. Light plastic raincoats are useful because they are very light and



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Plate 43A. Typical field clothing, and a common method of back-packing, with heavier articles in pack-sacks, and lighter sleeping bags carried above them. The man at left uses shoulder straps and a head-strap.



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Plate 43B. Back-packing, using pack-frames on which loads are lashed instead of being placed in pack-sacks.

compact; they may get torn but are so inexpensive that this is not serious.

Sweaters, Hats, Gloves

One or more woollen sweaters or heavy woollen shirts are required. Gloves or mitts are required for warmth in some regions, and during some seasons in any part of Canada. Heavy gloves are useful for protection when doing rough work such as removing large pieces of rock from a trench; for such work some prefer the waterproof workmen's gloves. Most prospectors wear a hat or cap, at least during very sunny or wet weather.

Sewing Kit

Needles, thread, darning wool, and spare buttons should be carried on long trips.

Bedding

Sleeping bags are generally preferred to blankets because of their lightness and because the end and sides can be fastened. A good combination for summer is a light bag and a blanket that can be put under the bag in two thicknesses on mild nights, and inside the bag on cold nights. Even when using a bag, it is desirable to have a tarpaulin 6 or 8 feet square to fold under and over the bed, unless one is sleeping in a tent with a canvas floor. Small air mattresses are fairly inexpensive and are worth including on all but back-packing trips. Mosquito netting, or a 'fly bar', is a necessity as protection against insects at night. It is light and inexpensive and can be rolled into a very small bundle.

Tents

For most camping trips a tent is desirable. The most popular tent for wooded country is the "A" shape, with side walls from 2 to 4 feet high and a wedge-shaped roof; for a very small, light tent the side walls are omitted. The usual size for one or two men is 7 by 9 or 8 by 10 feet in floor dimensions. The pyramid tent, requiring only one pole, is preferred for regions where poles are hard to find or where collapsible metal ones must be included in the outfit. Duck tents are relatively cheap, but the more expensive ones made of treated cotton (so-called silk tents) are lighter and more compact. For sleeping, green or khaki tents are darker than white ones. However, as white tents or tents of orange fluorescent nylon are much easier to locate from the air, they should be used if rendezvous with aircraft are to be made, unless the outfit includes other means of attracting attention. Tents equipped with sewn-in canvas floors and cheese-cloth fly doors are best for keeping out flies, mosquitos, and other pests, unless a wood stove is to be used in the tent. A light 'fly' to stretch over a tent keeps a tent from leaking and shades it, and can be carried instead of the tent on light trips.

Tarpaulins

Small canvas tarpaulins are useful for making shelters and covering equipment, firewood, etc. For light trips a few yards of thin plastic, such as can be bought cheaply by the yard in department stores, will take the place of tarpaulins.

Stove

A camp-fire is sufficient for light trips, but a small stove is desirable to permit cooking in the tent during rainy weather, and for warming and drying the tent. Small sheet-iron stoves come in different weights and sizes, the smallest being very light. They are of both collapsible and rigid types, the former are more compact but are sometimes difficult to assemble after they have been used for a time. About 2 inches of sand or earth must be placed in the bottom of the firebox to keep the metal from burning out; if the stove has an oven, a little sand or earth should be placed between the top of the oven and that of the stove, to hold the heat.

A gasoline or Primus stove is used where wood is difficult or impossible to obtain. Some campers prefer a gasoline stove even in wooded country.

Saw

A saw is useful for cutting firewood and for other uses around camp. A light one can be made by fastening strong iron rings about 1½ inches in diameter to the ends of a 'Swede saw' blade. A green pole about a foot longer than the blade is then sprung between the rings to maintain tension and provide a handle.

Dunnage Bags, Packsacks, etc.

For carrying small articles during the day a haversack or rucksack is almost a necessity. A haversack is easier to get at, and is suitable if only a few articles are carried, but it has the disadvantage of being apt to catch on branches, etc., because it is slung over one shoulder. A rucksack that is carried at the back, and slung from both shoulders, is better in all respects except that it has to be taken off every time anything is taken from it.

Canvas dunnage bags or packsacks are generally used for stowing and transporting camp equipment and spare clothing. For back-packing many woodsmen find a pack frame, to which articles are lashed, preferable to a packsack.

Provision Bags

Canvas sacks are needed for protecting food from dampness and for preventing damage to the light cloth or paper bags in which it is packed. They range in size from 50-pound ones for a sack of flour to 1-pound ones for small parcels. They can be bought already treated with paraffin to make them more waterproof than untreated canvas, or the user can treat them, or other canvas articles, by painting with a solution of paraffin wax in pure benzene or gasoline.

Illumination, Matches, etc.

Except in the north in midsummer a flashlight is almost indispensable. For illuminating tents, candles are usually taken on light trips, and small gasoline lanterns are often included in more elaborate outfits. At least one lighter or waterproof match safe should be carried at all times. Good match safes can be bought or they can be improvised by

placing matches in a tin and sealing it with adhesive tape, or by pouring melted candle wax into a box of matches. Match heads can also be waterproofed by dipping in shellac. It is advisable to stow water-proofed matches or matches in waterproof containers in several different bundles of equipment, so that if one is lost there will still be a supply.

Fishing Tackle

For most regions it is well to have at least a minimum of fishing tackle to obtain fish for food. Rods or other elaborate tackle are not essential. A few hooks, lures, and trolling lines are about all that is needed, but a small gill net is useful on long trips.

Firearms

Firearms are needed for protection in only a few parts of Canada. In almost all parts of the country there would be more danger from accidents with firearms than from wild animals. In some places a rifle is desirable for obtaining food or for killing black bears that may become a nuisance, rather than a menace to life.

Prospectors should acquaint themselves with local game laws. Information may be sought from local game wardens or from the provincial government departments responsible for game laws, or in the case of the Northwest Territories or Yukon from the administration of those territories. In parts of Canada one may carry a rifle without a permit, but special permits that are usually hard to obtain are necessary for carrying a revolver or pistol.

First Aid Kits

A small kit should be carried in the pocket at all times. A larger kit should be kept in camp; these can be made up to suit individual requirements or bought readymade, but in the latter case it is usually necessary to add a few household remedies, as most ready-made kits are intended for accidents rather than illnesses.

Rope and Wire

About 50 feet of light rope, such as sash-cord, is often useful. A small coil of thin brass or copper wire, such as is sold for snaring rabbits, is handy for making repairs and for obtaining food in emergencies. A little stove-pipe wire or hay wire may also prove useful. Pliers are worth taking on all but very light trips.

Miscellaneous

A few nails and rivets are useful for repairing equipment, and a pound or so of 2-inch and 4-inch nails are helpful in making camp. A roll of friction tape is a wise addition to most kits.

At least one knife is a necessity, and it is well to have a spare one. The choice between a pocket knife and a sheath knife is largely a matter of individual preference. A small whetstone should be included for long trips.

Persons who depend on spectacles should always carry a spare pair. Sun-glasses are necessary at times in mountainous areas and are otherwise often desirable. When sampling or drilling, the use of safety goggles is a cheap and effective protection against injury.

PROTECTION FROM FLIES AND MOSQUITOES

Mosquitoes, blackflies, and other biting flies are a nuisance in most parts of Canada during the summer months. In many places they are so numerous that even the most experienced woodsmen have to protect themselves. With the repellants available today there is no need for anyone to hesitate about prospecting because of these pests. To prevent repellents from running into the eyes it is advisable not to put any on the forehead; they may be smeared on the underside of the brim of a hat or cap to assist in keeping insects away.

On any but the lightest trip it is desirable to carry fly spray and a small sprayer, or a can containing an insecticide under pressure, for use in a tent. Such items are not so-called "luxuries" when it is realized that too much discomfort reduces efficiency.

PROVISIONS

The choice of provisions varies greatly with the method of transportation and length of trip. For many kinds of prospecting trips supplies are no great problem and no advice is necessary beyond pointing out the need for taking a reserve for emergencies. For any kind of trip it is unwise to count on obtaining fish or game; sufficient food should always be taken, and fish or game should be considered only as extras.

For long trips, unless frequent servicing is provided, it is usually necessary to avoid or restrict heavy or bulky foods such as canned fruits and vegetables, and to take only enough perishable foods to last for the first few days. An experienced man can live for a long time on a limited amount of staples that keep well, such as flour, bacon, baking powder, beans, salt, dried fruit, and tea, which provide a fairly well-balanced diet. When possible, however, a few additional items should be taken for variety. The following list is suggested as a basis for one man for a month:

Flour	25 lb
Baking powder	1 lb
Rolled oats (quick-cooking variety)	6 lb
Beans (dried)	5 lb
Rice	5 lb
Potatoes (dehydrated)	4 lb
Vegetables (dehydrated carrots, turnips, beans, etc.)	4 lb
Bacon and ham	20 lb
Cheese	3 lb
Egg powder	1 lb
Sugar	15 lb
Tea	1 lb
Coffee	3 lb
Chocolate (semi-sweet, for lunches and emergency)	2 lb
Milk (powdered whole milk)	3 lb
Salt	1 lb
Fruit (dehydrated prunes, peaches, apples, apricots, figs, raisins, etc.)	6 lb

Butter (canned)	4 lb
Jam, syrup, honey	5 lb
Pudding powders (prepared mixtures)	2 lb
Dehydrated soup mixes	1 lb
Yeast	–
Oranges	1 dozen
Canned fruit	6 tins
Canned sausage or beef	6 tins
Pepper, and other spices if desired	–
Lard (or substitute)	2 lb
Candles	½ dozen
Matches (these should be placed in two or more waterproof containers, which should be placed in different packs in case one is lost)	–
Small plastic bags (for lunches)	–
Soap, including toilet and laundry soap, soap-flakes or detergent	–

The items listed above would total about 125 pounds. Weight could be reduced by omitting some canned foods, and by using some of the 'instant' products now available in small envelopes. Bacon and ham should be of the canned or gelatin-packed varities if they are to be kept for more than a few weeks. Fresh or dried meat can sometimes be obtained locally, but this source should not be relied on.

UTENSILS

For an occasional short trip most persons could obtain utensils at home that would serve, but for steady use several items intended especially for camping are preferable. A wide choice is available, ranging from very light one-man kits weighing less than a pound to elaborate outfits. Pots should be of tin or aluminum for lightness, and should nest to save space. Plates, cups, and bowls may be of tin, aluminum, enamel, or plastic. The following would be a moderate outfit for two men and occasional visitors:

- Nest of 3 or 4 pots with lids
- 1 or 2 frying-pans
- 2 pans for baking bread, etc.
- 1 wire toaster
- 4 plates
- 3 cups
- 3 small bowls
- 1 lifter
- 1 whip or egg-beater for mixing milk
- 1 butcher knife
- 1 can opener
- 4 each knife, fork, and spoon
- Steel wool or equivalent for cleaning pots
- 2 yards dish towelling
- 1 large spoon

A dish pan, flour sifter, teapot, coffee pot and one or two pails might be added if weight and bulk were not serious problems.

PROSPECTING EQUIPMENT

The essential pieces of equipment for conventional prospecting, as distinct from travelling and camping, are not numerous. There is scope for a certain amount of individual preference even in the following list of more usual articles. It is not necessary to have all the items listed nor to carry all that one has at all times; a selection may be made to suit particular requirements. Equipment for preliminary exploration of a prospect is also mentioned. Special items for advanced prospecting are discussed in later chapters.

Prospecting Pick

A prospector's pick or rock hammer of some kind is the essential tool. The usual type is a short-handled one for use with one hand, having a head with a hammer at one end and a pick at the other. The hammer end, used for knocking off pieces of rock, should be square sided. Both the hammer and pick faces should be tempered as hard as possible without making the steel brittle. The eye should be as large as possible to reduce the chance of breaking the handle; a spare handle should be carried. A bricklayer's hammer is suitable for most purposes. Some prospectors prefer a long-handled pick with a head similar to an ordinary prospector's pick, because it necessitates less stooping and can also be used as a walking-stick to assist in climbing hills. A pick of this kind can be made from an ordinary prospector's pick and a sledge-hammer handle, but the eye is likely to be too small to prevent the handle from breaking under the blows that can be struck when such a tool is used with both hands; it is therefore better to have a blacksmith make a head with a large eye.

Grub-hoe

A prospector's grub-hoe is lighter than an ordinary grub-hoe and has one hammer face and one hoe face. Many prospectors have both a grub-hoe and a pick, and carry whichever seems to best suit immediate requirements.

Axe

An axe is of course necessary in the bush; the usual type has a 1-pound or 1½-pound head and about a 26-inch handle. A spare handle should be taken on long trips. A leather sheath protects the blade and prevents cuts to persons and equipment. It is desirable to have a single-cut flat file 6 or 8 inches long for sharpening the blade, as well as a whetstone. Some prospectors carry a small hatchet in a sheath on the belt, but most woodsmen consider an axe their most essential companion next to a supply of matches.

Radioactivity Detectors and Fluorescent Lamps

These special instruments for certain kinds of prospecting are discussed in Chapters 9, 11, and 12.

Gold-pan

Apart from its use in testing placer deposits, a gold-pan is very helpful in lode (hard rock) prospecting. Such use is by no means confined to gold. Crushed samples can be panned in the field to concentrate the heavier mineral grains, which are generally the important ones. In this way minerals that are too finely dispersed for detection in a solid specimen can often be found. Pans are of different sizes. The larger ones are generally used in placer work and smaller ones in lode prospecting.

Mortar and Pestle

Iron or steel mortars and pestles are useful for grinding samples at home or in camp; or a suitable mortar can be made from a 2-inch pipe cap or a piece of 2-inch pipe about 2 inches long with an end screwed or welded in



Plate 44
Examples of prospecting equipment and a chip-sample. 1, large gold-pan; 2, medium-size pan; 3, steel mortar and pestle; 4, grub-hoe; 5, long-handled prospecting pick; 6, ordinary prospecting pick; 7, rock chisel; 8, chip-sample; 9, single-jack; 10, moil; 11, canvas sample-bag; 12, goggles for protecting eyes when sampling.

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place, or from a piece of steel hollowed out on a lathe. A short piece of steel or a prospector's pick will serve as a pestle.

Sieve

A sieve is useful for screening a sample during crushing. Some authorities recommend a sieve having 60 or 80 apertures to an inch. A sieve can be improvised by punching small holes in the bottom of a small tin can, or by soldering a piece of fine-mesh screen to the bottom of a can whose ends have been removed.

Compass

A compass is an essential item that should be carried at all times to avoid getting lost, to aid in staking, and to help in making sketches and recording the strike of mineral deposits and other geological features. The best type for the purpose is a geologist's 'Brunton' compass, but good instruments of the army marching type can sometimes be found in second-hand stores; actually a one-dollar compass will serve.

On some compasses it is not clear which end of the needle points north. A sensible precaution is to test the compass where the direction is known, and scratch a note on the case, such as "blue north".

Map Case

A waterproof map case with a transparent plastic cover is sometimes desirable. The map can be cut in sections or folded to the proper size, keeping in mind that air photos are about 10 inches square.

Tape

A 50- or 100-foot 'metallic' tape is desirable in special cases where accurate measurements are to be taken. These are strong, treated cloth tapes that do not kink or break as readily as do steel ones; they may stretch slightly but this is not serious for the kinds of measurements involved.

Protractor and Scale

A protractor and a 6-inch scale are desirable for plotting points on a map and for making sketches. The scale should be divided into inches and tenths, or into divisions corresponding to the scale of the map most frequently used. Inexpensive protractors and scales can be bought in 'dime stores', and it is advisable to include spare ones as they are easily lost.

Pencils, Notebook, Paper

A few pencils, perhaps including coloured ones, are useful, as well as a small notebook. A pad of tracing paper about 8 by 10 inches with a sheet of square-ruled paper that can be slipped in is an aid in plotting. Felt-tipped marking pens have various uses including the numbering of sample bags.

Pocket Lens, Magnet

A lens is almost indispensable for examining specimens and pannings. An inexpensive single lens magnifying 4 to

5 times will suffice but many prefer a more costly compound lens magnifying 8 or 10 times.

A small alnico magnet should be carried for testing magnetic minerals and for removing them from pannings.

At least some of the following tools are required for the preliminary exposure of a discovery that seems to warrant such work and for assessment work. They might be kept at the base or in camp until needed, or one might return to do such work on another trip. Work of this type might never be necessary, or the prospector could have someone else do it for him.

Pick and Shovel

Both pick and shovel are useful in a multitude of ways, for trenching, removing overburden, etc.

Moils, Drill Steel, Hammers

Commonly used for sampling, moils are octagonal steel rods 8 to 12 inches long, with a hardened, 4-sided point. One type has a handle and detachable bits; a large cold-chisel may be used instead. They are struck with a small sledge hammer or a prospector's pick.

If trenches are to be excavated in solid rock, a few lengths of drill steel should be carried unless a power drill is used. Ordinary striking drills are usually made from about $\frac{3}{4}$- or $\frac{7}{8}$-inch octagonal steel, with a chisel-shaped bit. They range in length from about $1\frac{1}{2}$ to 3 feet, the longer ones having slightly narrower bits. The tops of drills and moils should be ground or forged occasionally to remove 'mushrooms' that might injure a hand if the tool slips. An iron rod with a small scoop at one end is required for removing rock cuttings from the holes drilled.

A man working alone uses a short-handled sledge weighing 2 to 4 pounds, holding the moil or drill in one hand and the sledge in the other; for this reason it is often called a 'single-jack'. When two men are working, one holds the drill and turns it slightly from time to time, and the other uses a long-handled sledge weighing about 8 pounds.

Explosives

Dynamite, caps, and fuse are required if trenching in solid rock is to be done. Regulations and precautions are discussed in Chapter XIV.

Portable Power Drills

Powered by a small mounted gasoline motor, portable power drills are now widely used for drilling blast-holes for rock trenching. They are fairly heavy and expensive, and are useful mainly for work undertaken by companies or by experienced prospectors who do fairly extensive exploration of a discovery.

Light Diamond Drills

These are used by some experienced prospectors for prospecting beneath a favourable structure, for preliminary exploration of a prospect, or for drilling blast-holes but are not part of most prospectors' equipment.

TRANSPORTATION

For all but casual prospecting, the methods of travelling and transporting equipment are of vital concern. They vary greatly for different parts of the country, and in many regions there is a certain amount of choice. In most instances there will be at least one geological report on the area or on one nearby. This should be consulted for information on the methods of reaching the area and travelling within it, although changes in roads or trails may be expected.

Southern Canada is fairly well served by railways and roads, from which much prospecting can be done by daily trips on foot or by short back-packing trips. In many places, branch roads that are unsuitable for ordinary automobiles can be travelled by truck or jeep, and tracked vehicles are sometimes used away from roads. Also, there are steamship services on the coasts and on some of the larger lakes and rivers. Road maps and other information of this kind can be obtained from the Canadian Government Travel Bureau, Ottawa, and from provincial or local travel bureaus. Readily accessible areas are, however, likely to have already been prospected fairly thoroughly. In general, therefore, prospectors have to transport themselves and their outfits as far as they can by rail, road, steamer, or airline and then rely on one or more of the methods discussed below. These methods are usually quite different in summer and winter. Only the summer methods are discussed, because most prospecting is done then; anyone engaging in the special kinds of prospecting that can be done in winter will probably be familiar with the methods of travel or know where to obtain advice. In most parts of the country there are intermediate seasons called 'break-up' and 'freeze-up', usually lasting a month or six weeks, when the ice is leaving or forming on lakes and streams. During these periods it is either impossible or inadvisable to travel. Most prospectors set out after break-up and return before freeze-up, but when it is necessary to spend as much time as possible in actual prospecting they may travel to their destination in the winter, even carrying a canoe on a dog-sled if necessary. Then they would remain inactive or prospect near their base camp during break-up and freeze-up, and return in winter. The length of the open summer season varies slightly from year to year, and is progressively shorter towards the north. In the more southerly regions the best prospecting season is generally from some time in May to about the end of October. In the vicinity of the Arctic Circle the open season is usually from some time in July to some time in October, but there have been occasional seasons when the ice did not leave Great Bear Lake, for example.

Canoes and Small Boats

In many parts of Canada the canoe is the basic means of summer travel. This is particularly true in the Canadian Shield, which is laced by a network of lakes and streams that permit access to within a few miles of most points. Furthermore, the streams of the Shield are characterized by long sluggish stretches separated by shorter rapids or

falls. Canoeing upstream is therefore usually not very arduous except for the necessity of poling or hauling the canoe up the lesser rapids and back-packing on the portages at the worst ones. The Indians adapted themselves to these conditions by trial and error centuries ago, developing the birch-bark canoe, which was light to paddle and to portage, and easy to repair. The early fur traders and explorers were quick to follow their example, and used the birch-bark canoe to open up all parts of the country except the west. For many years the canvas-covered canoe, because of its greater durability and stability, has replaced the birch-bark. Aluminum canoes have recently appeared on the market but have not become popular because they are harder to repair. Canoes made of plywood have been used with good results.

Canvas canoes come in many shapes and sizes. The most popular for average conditions is 16 or 17 feet long and of the 'prospector' or 'cruiser' model. The former is lighter, and flatter bottomed. The cruiser is a little sturdier and has a rounded bottom that permits larger loads. A round bottom makes a canoe easier to paddle, but a flat one is best for shallow streams and for quick manoeuvring in rapids. For carrying larger loads and for greater stability on large lakes the 'freighter' model is preferable. It is made in lengths of 18, 20, and 22 feet, but the 18-foot type is the only one that is usually portaged, and even this is an awkward load for two men. 'Semi-freighters' are also made, the construction being lighter than that of 'freighters'.



G. W. H. Norman 78111

Plate 45A. A lone prospector and his 14-foot canoe, Chibougamau region, Quebec.



C. H. Stockwell 76327

Plate 45B. The one-man method of portaging a canoe. This photograph was taken in Yellowknife region, N.W.T. in the spring, before all the ice had melted.



A. H. Lang

Plate 46. Outboard-motor boat of type commonly used on larger lakes and rivers in B.C. and Yukon when portaging is not necessary.

An experienced canoeist travelling alone with a light outfit may use a canoe 14 or 15 feet long but 16- or 17-foot canoes are generally recommended, or larger ones if portages are not a problem. One man can portage a canoe up to 17 feet long by lashing the paddles across the bars with the blades near the centre of gravity; the canoe is then turned upside down over the head, and the blades rest on the shoulders.

A spare paddle, a tube of waterproof cement, and a piece of canvas for patches should always be carried in a canoe. In some provinces, regulations require that a kapok-filled life-vest be kept in the canoe.

A 17-foot prospector canoe weighs about 75 pounds when new and will carry about 600 pounds. An 18-foot freighter weighs 90 to 130 pounds and will carry 900 to 1,700 pounds. Canoes should be painted orange or some other bright colour to make them easy to locate.

Sectional and collapsible canoes are made for carrying in the cabins of aircraft, but are now seldom seen because ordinary canoes can be carried by some aircraft. Row-boats and car-top boats, etc., are satisfactory for use on lakes but are not suitable for portaging. Pneumatic boats for use with outboard motors are convenient for transport by aircraft or truck. In western Canada, where the rivers are usually swift, the customary craft, if a river can be navigated at all, is a locally built, flat-bottomed wooden boat 20 to 30 feet long, used with a powerful outboard motor (*see* Pl. 46); these are much like the boats called 'pointers' used on large rivers in eastern Canada.

Inexperienced persons should not attempt to travel by canoe or boat unless accompanied by an experienced man.



A. H. Lang

Plate 47A. A freighter canoe being lined along a rapid too swift for the outboard motor, which is out of sight at the stern.

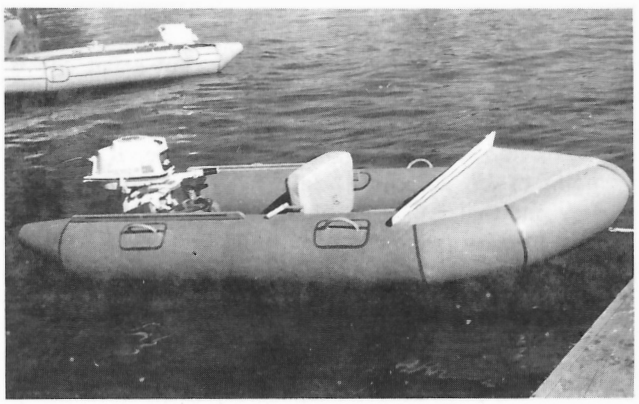


Plate 47B. Pneumatic boats (courtesy Canova Products).

If this is not feasible, they should get someone to give them basic instruction before setting out.

Rafts

When nothing else is available, a strong raft may be used on a river or lake. Rafting should not be attempted on too swift a stream and the raft must be large enough for buoyancy and strong enough to hold together. A raft should be rectangular rather than square, to make it easier to steer. A raft of four dry, 6- to 8-inch logs 10 feet long will support one man.

Outboard Motors

Outboard motors are now widely used on canoes, and almost invariably on the kinds of boats that might be used by prospectors. When there are few portages a motor adds to the speed and ease of travel, but the reverse can be true if frequent portaging of a motor and fuel is necessary.

Small Vessel Regulations of the Canada Shipping Act are summarized in "Safety Afloat", a booklet available free of charge from the federal Department of Transport. Any person using a boat, powered or not, could save himself embarrassment and a possible fine by examining these regulations.

Considerations in selection of a motor are lightness of weight and its horsepower capacity related to the size and weight of the canoe. Motors are too powerful for canoes less than 16 feet long. For 16- to 17-foot canoes, 2- to 3-hp motors are generally used, and 4- to 6-hp for 18-foot freighters. Brackets for fastening motors to sharp-sterned canoes are available, but canoes for use with motors are now usually flat-sterned and may also be paddled.

It would be advisable to consult a dealer about spare parts, tools, and making repairs. Once away from commercial centres a motor breakdown due to lack of parts or knowledge could become a serious problem. If a large party takes more than one motor, they should be of the same type so that parts from one could be used to repair another if necessary.

Aircraft

In recent years aircraft have been used increasingly in connection with prospecting and mining and they are contributing greatly to the development of otherwise inaccessible regions. The Canadian Shield is particularly suited for aircraft equipped with floats, or flying boats, because of the innumerable landing places afforded by lakes and rivers. Many prospecting parties avoid long canoe trips by being flown with their outfits to the chosen area, and arranging to be brought back or moved elsewhere at an appropriate time. Charter services operate from many towns, and advertisements in the mining press give the



J. F. Henderson 81770

Plate 48. The method of lashing a canoe to a seaplane now widely used when moving prospecting and surveying parties, particularly in the Canadian Shield.

names and locations of several. In 1967 charges were roughly $50 to $100 an hour or .50 cents to $1.25 a mile depending on size of aircraft and location, but prices are changeable. Aircraft generally used range from small ones that carry two men and a little baggage to medium-sized ones that can carry 1,000 to 2,000 pounds, including a canoe lashed to float struts. Canoes used on trips of this kind are usually 16 or 17 feet long. Prospectors and geologists who travel by aircraft commonly develop skill in observing and sketching from the air, which assists greatly in detecting and interpreting geological features, selecting routes for travel on the ground, picking campsites, and so on.

Several prospecting and mining companies own their own aircraft or charter them for long periods. This not only facilitates the moving and servicing of prospecting parties, but also permits supervisors to visit them regularly. A few independent prospectors fly their own aircraft. This is a great advantage, and the number of such prospectors will probably increase. However, a private pilot cannot operate safely in this way without special instruction and qualifications. Bush flying was pioneered by a small group of skilled pilots after World War I, using aircraft that now seem very inadequate. Worthy successors to these men have brought bush flying to a high degree of safety and efficiency by learning not only the specialties of flying from water but also those of flying in regions for which there are no detailed maps or other aids to navigation.

In places where landings cannot be made, particularly in mountainous parts of western Canada, supplies and equipment are dropped by parachute, for both prospecting and geological survey parties.

Helicopters have proved successful for certain uses in prospecting and geological surveying. They can land at many places where conventional aircraft cannot, and their ability to hover facilitates close observation from the air. Their main disadvantages are their expense, and the limited range and carrying capacity of the smaller types.



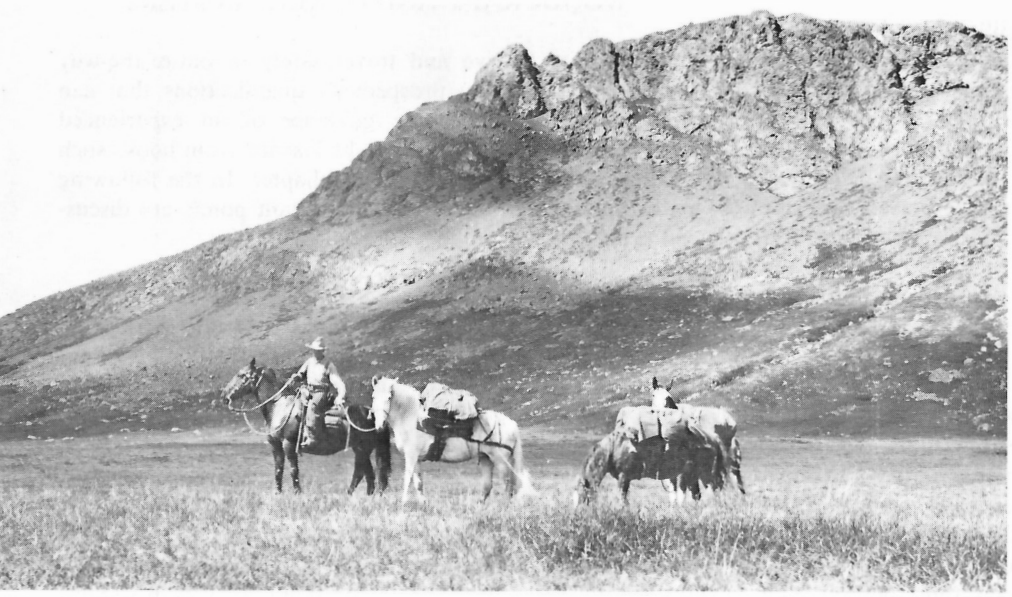
G. B. Leech 7-4-53

Plate 49. Tying a diamond hitch.

If an aircraft is to return to bring supplies or to move a prospector or party, detailed arrangements should be made in advance. If possible, written instructions, including date and details of such matters as smoke signals, and a map or sketch showing the rendezvous or route to be covered on the ground, should be left with the office of the flying company or with a third party. This is advisable in case a pilot might forget oral instructions, lose written ones, or have an accident on his way to his base after placing a prospector or party in the field and after agreeing on a future rendezvous.

Horses

Pack horses were the most suitable means of transport in many parts of the Cordilleran region but have now



A. H. Lang 85978

Plate 50
Pack horses in Driftwood Mountains, near Smithers, B.C.



Plate 51
Horses being made to swim across a large river in British Columbia. A led horse is being guided with a canoe as an example for the others.

A. H. Lang 89566

largely been replaced by jeeps, helicopters, and other equipment. They were seldom used elsewhere because better transportation was generally available. Few parts of the Shield are suitable for horses because the irregular pattern of lakes, streams and muskeg prohibits travel on a direct overland route, and because of lack of feed. In the west there are many places where trails are accessible or can be cut, or where trees are sparse enough to permit travel without trails, and where mountainsides are not too steep for a horse. In many western areas outfitters and hunting guides will transport prospecting parties, make servicing trips, or rent horses to experienced men.

The third edition of this book, which is available in libraries, contains a more detailed discussion of the use of horses.

Dogs

In the northern parts of the Cordilleran region and the Canadian Shield, sled-dogs are commonly used in summer by natives for carrying packs weighing as much as 50 pounds. This method is sometimes used by prospectors and survey parties in places where trees are too dense for pack horses or where water routes are lacking. The load is placed in pockets in a canvas pannier placed over the dog's back. The disadvantages of this method are that dogs are inclined to stray from the route and to engage in fights, and also that they have to be provided with food.

Back-packing

Almost every prospector has to resort to back-packing at times, either for camping trips where no other method is available, for portaging, or for taking equipment to, or samples from, a discovery under investigation. With proper equipment it is not very difficult to carry enough for a trip lasting a few days, but packing heavier loads is gruelling work. For packing all day, 60 pounds is about the limit for the average man, but for short periods such as in portaging an average load is about 150 pounds and usually consists of one main pack with sacks piled above it (*see* Pl. 43A). The main pack is either a packsack, a pack frame, or a large sack or bale to which a tump-line is attached. The packsack usually has a head strap as well as shoulder straps, so that part of the weight can be taken by the forehead. A pack frame (*see* Pl. 43B) is often preferred for awkward loads like outboard motors, although seldom used for portaging.

Winter Equipment

Dog-sleds, snowmobiles, and winterized tractor trailers used for special prospecting surveys are used in winter but are too specialized for description here.

WOODCRAFT AND OTHER MATTERS

The ability to live and travel safely in out-of-the-way places is a part of a prospector's qualifications that can best be learned under the guidance of an experienced woodsman, although much can be learned from books such as those listed at the end of this chapter. In the following paragraphs a few of the most important points are discussed briefly.

Companions

Only the most experienced men should travel alone in remote places. A prospecting party, therefore, usually consists of two or more men, but they may separate for a few hours or a day.

Camping

The main factors in the selection of a campsite are usually availability of water, firewood, and tent poles. In most unsettled regions the water of lakes and streams is suitable for drinking, but in some small lakes or in streams

Plate 52. A light camp in Yukon territory. Note shelter made with canvas tarpaulin, extension placed on handle of frying-pan for use over open fire, fire-place in safe area of rocks and gravel, and dogs used to assist in packing (courtesy National Film Board).

draining swamps or beaver ponds it is unsafe. In settled areas it may be dangerous. Doubtful water should be boiled before use. In some areas it may be desirable to carry water for use during the day.

If possible, tents should be pitched away from large trees that may blow down in a storm, and on gravelly ground that will drain readily. Tents placed in depressions or on clayey ground may be flooded during heavy rain, unless trenches are dug around them.

Camps should be kept in sanitary condition and the sites should be left clear of rubbish; latrines should be covered with earth, and garbage burned, to keep down disease-spreading flies.



A. H. Lang 7-1-1931

Plate 53. Cache for storing provisions away from the reach of animals.

Small 'meat tents' made of cloth netting are useful for suspending from a tripod or from a pole attached to two trees, but it is difficult to make such contrivances proof against bears.

Food should therefore be kept in covered boxes or otherwise protected. Porcupines will destroy anything salty, such as leather, or axe handles or paddles that have received salt from perspiring hands, so such articles should not be left where porcupines can reach them. Black bears as a rule do not raid a camp that is only left for the day, but they often destroy everything in a camp that has been left for a few days and has lost its man scent. To protect a small amount of provisions from bears the supplies may be placed in bags or boxes protected by a tarpaulin and slung from a bar placed between two trees far enough apart so that a bear cannot climb the tree and reach the rope. A larger cache is made by selecting three or four trees placed so as to form a triangle or square with sides 6 to 10 feet apart. The trees are cut off about 8 feet from the ground, the stumps are barked to make them hard for a bear to climb, and a platform is made of poles, supported by the stumps. The supplies are piled in the centre of the platform and a tarpaulin is lashed over them. As an added precaution the platform may project 2 or 3 feet beyond the stumps, so that even if a bear climbs a stump it will be difficult for him to get on the platform.

Getting Lost

Everyone who enters the woods should know how to avoid getting lost and what to do if lost or injured. These

misfortunes do not happen often, but they do occur and may have serious consequences. The surest way of not getting lost is to make a pace and compass traverse right from the outset, by the method explained elsewhere, and to figure out the return course when the time comes. This is seldom necessary, however, when roving in the way usual for prospecting. If a traverse (*see* Chapter 9) is not made, the general direction should be noted when setting out by consulting map and compass, and by memorizing any prominent landmarks. As the day progresses, note the direction of tree shadows if the sun is out, and the position of the sun, take occasional compass readings, and if possible check landmarks or watch for new ones whenever open places are reached. When returning, if landmarks do not suffice the compass will give the general direction until familiar features are seen. It is advisable to blaze trees in the vicinity of camp or the place where a car or canoe is left to help guide one to the exact spot, as it is easy to 'overshoot' by reaching a road or shore in such a way as to miss the point desired. It is also helpful to make occasional blazes during the day.

When using a compass it is important to keep it away from metal objects that might cause inaccurate readings, as explained in connection with surveying. Occasionally a compass is affected by bodies of magnetic rock, so as to give completely erroneous readings. All that can be done to prevent this is to avoid using the compass near exposures of rocks that might be magnetic, such as gabbro or occurrences containing magnetite or pyrrhotite, and to check the evidence of the compass against that of the sun, shadows, or landmarks, and to take 'backsights' if a careful traverse is being made. In almost all cases, however, the observer, rather than the compass, is the more likely to be wrong.

If the traveller becomes completely lost, it is best not to try to travel in the dark, but to build a fire and rest. It is most important not to panic or waste energy. With daylight, calm observation may clear matters up. If the lost or injured person has companions in the district, the others are sure to search, and will probably detect a fire at night if it is built on a high place, or a smudge during the day; or they may themselves light a fire or smudge as a guide; it may also be possible to signal with a mirror or other reflecting surface. If there is any likelihood of a search by air or of attracting a passing aircraft, a large smudge should be prepared, ready to be lighted as soon as a plane is heard; the reflecting technique may also be useful. If at all possible, select an open place for signals so that they can be seen from an aircraft.

Men have lived on nothing but water for many days, and it is often possible to find some sort of food such as edible berries or roots, or small game. It is useful to carry a few hooks, a fishing line, and a coil of 'rabbit wire' whenever in the woods, as the line and wire have many everyday uses, and may prove invaluable. A man with poor vision was the object of a search for no other reason than that a twig brushed his spectacles off and he could not find them.

Fire Prevention

Apart from general conservation, there are many reasons why prospectors should be extremely careful to avoid setting fires and to put out any small ones encountered. The main causes of fires are carelessness when smoking and with campfires and smudges. Fires should be built close to water if possible, on large areas clear of all inflammable material including humus, roots, moss, etc., and they should be put out thoroughly. In this connection, it is important to remember that a fire will often smoulder long after it is thought to be out, particularly if humus or peaty material is present. Partly burned sticks should be thrown into the water or heaped with earth, because they will often flare up again after water has been poured on them.

In many parts of the country no one is permitted to travel in the woods without a permit from a forest ranger or other forestry official.

Suggestions for Additional Reading

Chief Inspector of Explosives, Department of Energy, Mines and Resources, Ottawa. Various publications relating to explosives.

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8

maps, reports, and air photos

Many kinds of maps, plans, and reports are used in prospecting and mining. Air photographs are also helpful for various purposes. This chapter explains briefly the main kinds of materials available, the ways in which they are used, and the means of obtaining published material.

Maps, plans, and reports are of two main kinds. One kind comprises publications, which generally result from government surveys, research projects, and compilations. The other kind consists of private material produced by companies or by persons working for companies. These are usually prepared for limited distribution, reports generally being typewritten or reproduced in some way such as mimeographing, and maps or plans generally being reproduced by blueprinting or some such process. This chapter deals mainly with the kinds of government publications that are most used in connection with prospecting.

GENERAL CHARACTERS OF MAPS AND PLANS

A map is a representation of a part of the earth's surface, drawn on a flat sheet of paper. Plans are representations of small areas, generally on much larger scales than maps. Because the earth is essentially round, and a map is flat, it is necessary to use some form of projection of points on the earth's surface onto a plane that represents the map. Most of the projections that may be used cause real or imaginary straight lines on the earth's surface to appear as curves or converging lines on the map. These are not noticeable, however, if the area represented by the map is only a few square miles.

A drawing showing the elevations at various points along a line crossing part of the earth's surface is called a *profile*. A drawing illustrating the conditions along a vertical plane 'cutting' part of the earth's surface is called a *section*. If the plane is at right angles to the general strike of formations or other features it is called a *cross-section* and, if parallel with them, a *longitudinal section*. Many sections include a profile at their top.

Vital considerations that should always be noted before the more detailed information of a map or plan is used are the name of the person or organization responsible, the date of issue, the orientation, and the scale. A map bearing a fairly early date may still contain much useful information, and this may be all that is available, but the user must expect that features such as roads or mining properties may have been established after the survey was made. Most maps are drawn so that north is at the top, but this is not always so. The orientation can be learned from the 'parallels' and 'meridians' representing latitudes and longitudes, or from arrows indicating true and magnetic north and the *declination* between them. Plans are commonly oriented northerly but many are drawn with other convenient orientations. Scales are very important and are discussed in the next paragraph.

Scales

The scale of a map may be shown in three different ways, all of which are often included on a map. One way is to state the relationship between inches on the map and feet or miles for an equivalent distance on the ground, such as "1 inch to 1,000 feet", or "2 inches to 1 mile". Another way is to place a line, called a 'bar scale' on the map, and to mark along it appropriate distances in feet or miles. The distance between two points on the map can be marked along the edge of a piece of paper, the paper can then be laid along the bar scale, and the distance can thus be determined; or a pair of 'dividers' may be used. Errors in the use of such scales are sometimes made if one fails to notice that many bar scales do not begin with zero, but have a section divided into smaller units placed to the left of zero. The third way of showing the scale is by a fraction showing the relationship between any distance on the map and an equivalent distance on the land; thus $\frac{1}{63,360}$, the fractional scale of a map on the scale of 1 inch to 1 mile, indicates that any distance on the ground is 63,360 times the equivalent distance on the map. Scales are commonly referred to as small, medium, or large. Confusion sometimes arises because these expressions refer to the size of the fractional scale; thus the relation between the map and the area mapped is greater for a large scale than for a small scale. In other words, the greater the denominator of the fraction, the smaller the scale.

Protection of Maps

A map used to any extent in the field should be protected from wear, weather, soiling, and loss of any notes added to it. One way is to use a map-case (*see* Chapter 7). Another is to mount the map entirely on cotton cloth or to cut it into sections and mount them on cards, or in a note-book, or in sections a quarter inch apart on a single piece of cloth which can then be folded between the sections. To mount on cardboard, soak the map sections and the cardboard in water, then apply paste thinly while they are wet. To mount on cloth, stretch a piece of cotton a little larger than the entire map by tacking it to a smooth wooden surface, spacing the tacks an inch or 2 inches apart. Wet the cloth and the map sections in water, apply a thin coat of paste to both paper and cloth, and press the sections to the cloth.

The surface of a map may be sprayed with a clear waterproofing compound, but this makes it difficult to add notes or other data afterwards with a pen or pencil.

TOPOGRAPHIC MAPS

A topographic map is a representation to scale of such features as lakes, streams, roads, railways, and towns. Many topographic maps are wholly or partly coloured, different tints being used for areas covered by water, forests, etc. Topographic maps also commonly indicate the *relief*, that is, the heights of various places above sea level. The degree of accuracy of a topographic map depends on the amount of time spent in surveying, on the methods used, and on the scale, because large-scale maps are usually made with greater precision. Many geological maps also show topographic features, and thus it is often unnecessary to use both a topographic and a geological map. Therefore part of this discussion is also applicable to geological and other kinds of maps.

Relief

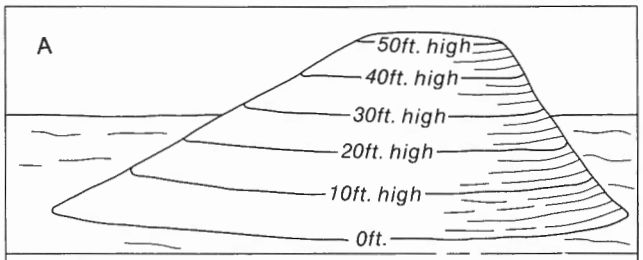
Prospectors should be familiar with the ways by which the slopes and heights of landforms are shown because the relief indicates the amount and difficulty of climbing that may be necessary. Another reason is that the tracing of such geological features as veins, faults, or contacts is greatly affected by the slope of the land-surface, except in cases where these features are vertical, because the intersection of a vertical plane with a sloping surface does not bend with the slope.

Landforms and their heights above sea level are usually shown on a topographic map by *contour* lines, which are lines joining points having equal elevations above sea level, such as tens or hundreds or thousands of feet, depending on the ruggedness of the region and the amount of detail the map is intended to show. A beginner can learn to visualize the relief indicated by imagining that each line represents what a shoreline or island would look like if the land were flooded at heights corresponding to the contour intervals (*see* Fig. 15). On some maps different tints are used to show clearly the areas between different contours. Other ways of indicating relief sometimes used instead of contours are shadings and a special kind of short lines called 'hachures'.

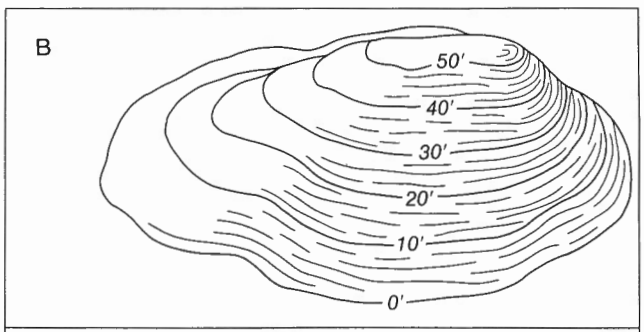
Land Subdivisions

Most parts of southern Canada have been divided into units, indicated on the ground by surveyed lines and corner markings of various kinds. These subdivisions are usually shown on topographic maps, and it is important for prospectors to understand them because they are helpful in locating positions, describing discoveries, and staking claims.

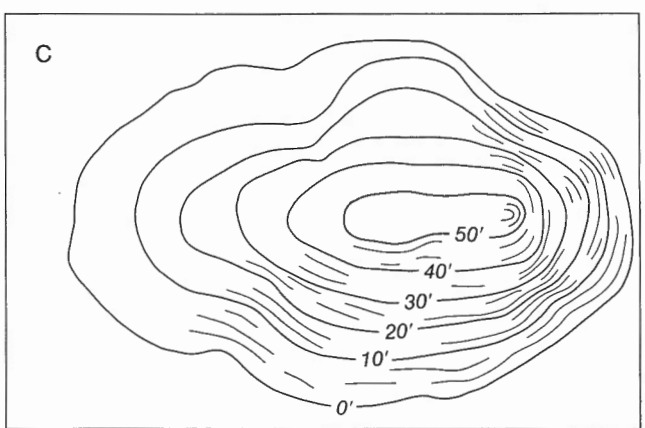
In Eastern Canada the largest land units are usually called counties or districts. These are divided into townships, which are commonly 10 miles square. In districts surveyed many years ago the townships are usually laid



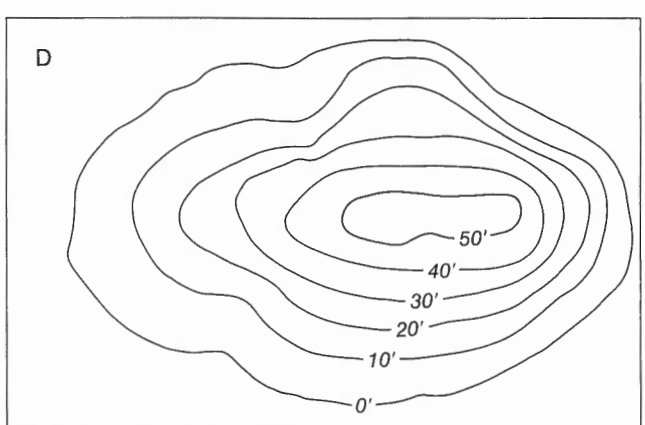
The shoreline of a hill-shaped island is indicated as the base or zero contour. Imaginary shorelines that would be formed if the water rose at 10-foot intervals are also drawn.



A more oblique view of the same shorelines.



Top view of the same shorelines.



Contours equivalent to the shorelines of drawing C.

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Figure 15. Explanation of contours.

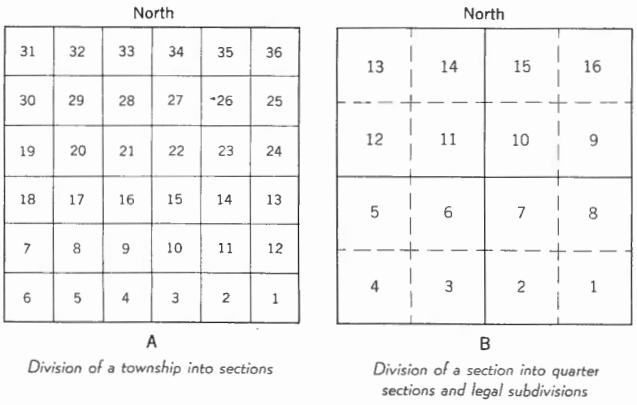


Figure 16. The division of a township into sections, etc. according to the Dominion Lands System.

out irregularly, but in those surveyed more recently the lines usually run north-south or east-west. Townships may be named or numbered. They are usually divided into strips one mile wide, called 'concessions' in Ontario and 'ranges' in Quebec, extending east and west, and numbered consecutively from south to north by Roman numerals. These strips are divided into lots, commonly numbered in Arabic numerals from east to west. Thus the description of a lot might read "Lot 16, Concession IV, Percy Township, Northumberland County". In some of the more recently surveyed parts of Ontario the Dominion Lands System explained below is used, and in some of the older parts of Quebec 'parishes' take the place of townships.

In the Dominion Lands System, used in most parts of western Canada, the townships are 6 miles square. They are numbered, and their position is referred to a series of meridians extending northward. The First or Principal Meridian was laid out from a starting point selected near Winnipeg; its longitude was later determined to be 97 degrees 27½ minutes west of Greenwich, to which all longitudes are referred. The other meridians are at regular intervals of 4 degrees of longitude. Rows of townships extending northward are called Ranges, which are numbered successively away from the meridians, in Roman numerals. Townships are numbered northward from the 49th parallel, in Arabic numerals. Each township is divided into sections one mile square, as shown on Figure 16A. Each section is divided into quarter sections, each of which is divisible into quarters called 'legal subdivisions', as shown on Figure 16B. Thus the description of a piece of land might read LS 14, Section 12, Township 2, Range III, west of the 1st Meridian. In British Columbia, townships are laid out in somewhat the same fashion as in the Dominion Lands System, but are subdivided differently.

Grid Reference

On some topographic maps, numbered or lettered intervals are marked along the borders, to which any place on the map can be referred by drawing lines north, south, east, or west to the edges of the map. The approximate position of the point can then be described from the grid intervals intersected. Another method is to draw pencil lines across the map, through the grid markings, thus dividing the map into a series of small squares. If desired, a map that does not have grid markings can be gridded by drawing lines, say, one inch apart, and numbering or lettering them.

Federal Topographic Maps

The Topographical Survey of the Department of Energy, Mines and Resources issues topographic maps for many parts of Canada. Most are in the National Topographic Series, numbered as explained on Figure 17. The earlier maps of this series were on scales of 1, 2, 4, or 8 miles to 1 inch. More recent ones are on fractional scales of $\frac{1}{50,000}$, $\frac{1}{125,000}$, $\frac{1}{250,000}$, and $\frac{1}{1,000,000}$. These correspond approximately to 1, 2, 4, and 16 miles to 1 inch. The scales of such maps can be converted to feet or miles by dividing the lower figure by 12 (the number of inches in a foot), for example, $\frac{1}{50,000}$ equals $\frac{1}{12 \times 4166}$.

Federal topographic maps generally should be ordered from the Director, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; branch offices of the Geological Survey of Canada can supply certain maps of areas in their general region. Delay and needless clerical work is caused by ordering topographic maps from the head office of the Geological Survey of Canada. Index maps showing available maps are obtainable, or a map may be ordered by specifying the exact locality desired and the scale preferred. The charge for most maps is $1.00 each.

Provincial Topographic Maps

Topographic maps of certain areas are issued by provincial government departments, particularly the lands departments or branches of British Columbia, Ontario, and Quebec.

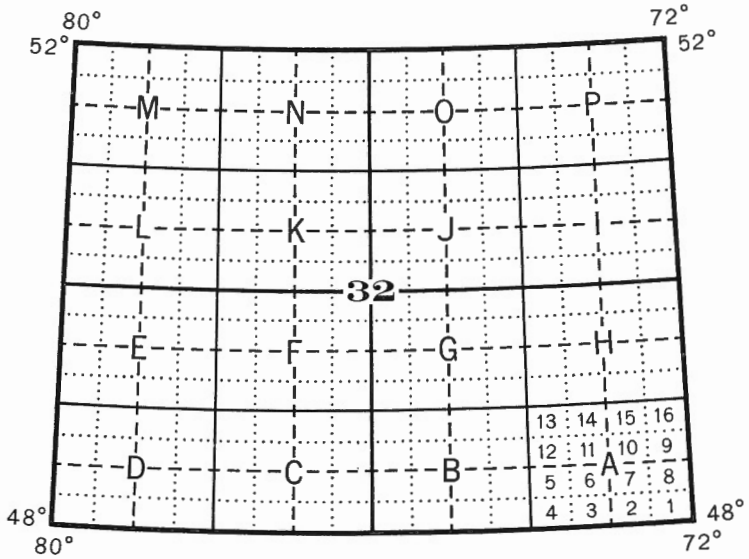
Suggestions for Additional Reading

How to order a topographic map; Surveys and Mapping Branch, Department of Energy, Mines and Resources.

GEOLOGICAL MAPS

A standard geological map shows observed and inferred information on the kinds of rock exposed in the area concerned and underlying it, and on the distribution and structures of the rocks. This information is usually added to a topographic base map, but commonly some topographic details must be omitted to permit clear presentation of geological data. Geological maps of another kind, called *surficial* maps, illustrate the kinds and distribution of such glacial deposits as sand, gravel, clay, and eskers.

The kinds of rocks and their distribution are shown by different colours or different patterns. These are standardized to some extent but full standardization is impracticable, and therefore the legend of the map must be consulted. Colours are preferable, but patterned maps can be published more cheaply and quickly. Users of patterned maps



The units consist of sheets, 4 degrees in latitude by 8 degrees in longitude, published on the scale of 1:1,000,000 (approximately 1 inch to 16 miles) shown on the index thus **32**

Each 1:1,000,000 sheet is quartered into sheets 2 degrees in latitude by 4 degrees in longitude, published on the scale of 1 inch to 8 miles (1:506,880), and referred to as N.W., N.E., S.W. or S.E., the number taking the form thus. . . . . . **32** S.E.

Each 1:1,000,000 sheet is divided into sixteen sheets 1 degree in latitude by 2 degrees in longitude, published on the scale of 1 inch to 4 miles (1:253,440) or 1:250,000, lettered from A to P, shown on the index thus. . . . . . **32** A

Each four-mile sheet (or 1:250,000) is quartered into sheets 30 minutes in latitude by 1 degree in longitude, published on the scale of 1 inch to 2 miles (1:126,720), referred to as N.W., N.E., S.W. or S.E., the number taking the form thus . . . . . **32** $\frac{\text{A}}{\text{S.E.}}$

Each four-mile sheet (or 1:250,000) is divided into sixteen sheets, 15 minutes in latitude by 30 minutes in longitude, published on the scale of 1 inch to 1 mile (1:63,360) or 1:50,000, the number taking the form thus. . . . . . **32** $\frac{\text{A}}{2}$

Note: Some one-mile maps and most 1:50,000 maps are published in two halves, referred to as east half or west half, the number taking the form thus. . . . . . **32** $\frac{\text{A}}{2}$ West Half

Every sheet is given a name indicating its location by reference to the largest city or town in it, or by reference to some well known geographical feature.

A map entitled "Index Map of Canada According to the National Topographical System", showing the extension of the numbering system for all parts of Canada, may be obtained from the Director, Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.

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Figure 17
Diagram showing method of numbering map-sheets of various scales, according to the National Topographical System.

often colour them, or parts of them, with coloured pencils. On many maps, outcrops and larger rocky areas are shown by symbols, and on a few detailed maps they are shown in deeper shades of the same colour as is used to depict the more extensive areas where the formation beneath overburden can only be inferred. Structural features are indicated by symbols to represent strike and dip, schistosity, faults, axes of folds, etc.

It is impossible to show all details on a geological map; one colour or one pattern therefore commonly represents rocks of several related kinds, or ages, and many minor faults, fractures, or other features are usually omitted. Mineral occurrences, mines, oil wells, and other relevant features known at the date the map was prepared are usually indicated. If an area contains many mineral deposits and occurrences, the practice is to show the more important deposits on the map and to refer to others in a report, if one accompanies the map; but it is not likely that all minor occurrences would be mentioned. If mineral occurrences of probable significance or interest are discovered during a geological survey, the location and kind are either shown on the map or mentioned in a report.

Many maps are accompanied by one or more structural cross-sections illustrating, perhaps only speculatively, the subsurface distribution of rocks. A legend for the map and sections explains the meaning of colours, patterns, and symbols, and is usually arranged to show the formations in the order of their ages, the youngest being at the top. Many maps are accompanied by marginal notes that provide short accounts of the topography, geology, and known mineral occurrences of interest. The name of the geologist (or geologists) who performed the field work and prepared the map is always stated on the map, because the authors of geological maps and reports are responsible for much interpretation as well as for the gathering of facts. The related report, if any, is usually indicated on the map.

Scales and Kinds of Geological Maps

Most of the coloured maps published in recent years by the Geological Survey of Canada are on scales of 1 inch to 1 mile and 1 inch to 4 miles, these now being standard for fairly detailed and semi-reconnaissance work, respectively. Preliminary maps may be issued on the same scales, or on scales of 1 inch to ½ mile and 1 inch to 2 miles. Less detailed reconnaissances may be published on still smaller scales. The results of special detailed investigations are usually published on scales of from 1 inch to 400 feet to 1 inch to 1,000 feet.

The Geological Survey also prepares and publishes compilation maps that co-ordinate information published on other more detailed maps. Examples are the series of regional maps on the scales of 1 inch to 8 miles and 1:1,000,000.

During its long existence the Geological Survey of Canada has mapped thousands of areas, and provincial organizations have mapped many others, but because of the vastness of Canada, and the relatively small staffs available for the work, much of the country has been covered only by reconnaissance geological surveys. More territory has been mapped in semi-reconnaissance ways, but the area for which mapping on the scale of 1 inch to 1 mile has been done by what are now considered adequate standards is very small indeed. With present staffs only a slight net improvement is possible each year, because maps made some time ago are becoming obsolete almost as rapidly as new 1-mile or more detailed projects are completed.

Interpretation of Geological Maps

The accuracy and amount of detail of the geological information shown on a geological map varies with the scale and purpose of the map, the number of rock exposures examined, the method used for surveying their positions, and the skill of the geologist and his assistants. Only in the most detailed forms of mapping, or in areas where outcrops are very scarce, is it possible to examine more than a small fraction of the rock exposures present. Even those that are studied may be open to more than one interpretation. For example, an area may contain two ages of granitic intrusions that are so much alike that only certain exposures can be mapped as definitely one or the other, and elsewhere the geologist has to use his judgment; or an area may contain two formations that are of the same kind of rock but of quite different ages, and in such cases errors or uncertainties in correlation can easily occur unless fossils whose ages are known definitely are found; or an area may contain more small plutonic bodies than could be detected by the method of surveying.

A geological map is, accordingly, a combination of facts and inferences. To use a map properly a prospector should be careful to observe whether outcrops are shown at or near the locality he is studying, and whether geological contacts, faults, etc., are shown as 'defined', 'approximate', or 'inferred'. A defined contact or fault, shown by a continuous line, usually appears within an eighth of an inch of its true position on the map. An approximate one is known to occur somewhere in the vicinity shown. An inferred one is either very indefinitely located or may not even exist.

Geological or 'structure' sections, since they depict the geologist's interpretation of conditions at depth, are usually much more uncertain than the map itself, because there may be changes with depth that no amount of surface study or drilling can reveal.

Despite the imperfections mentioned above, geological maps are universally recognized as being of the greatest assistance to prospectors and in the planning and locating of advanced prospecting projects, many cases being recorded in which mineral deposits were found with their aid. The ways of obtaining these maps are similar to those for obtaining reports, as explained in the following section. Index maps showing areas covered at different scales are available from the Geological Survey of Canada and from several provincial geological organizations.

Suggestions for Additional Reading

Blyth, F.G.
1965: Geological maps and their interpretation; Edward Arnold, London.
A well-illustrated paperback.

Dake, C.L., and Brown, J.S.
1925: Interpretation of topographic and geologic maps; McGraw-Hill.
A book on the interpretation of topographic and geological maps. Intended for fairly advanced students with a knowledge of elementary geology and trigonometry.

AEROMAGNETIC MAPS

A series of aeromagnetic maps, usually on a scale of 1 mile to 1 inch, is being published partly by the Geological Survey of Canada and partly under a joint federal–provincial program. These maps are useful for supplementing knowledge of the geology obtained by geological surveys, particularly in extending geological inferences beneath places covered by overburden. They are also useful in the selection of areas for advanced prospecting programs, and they may indicate favourable conditions that can be interpreted by skilled conventional prospectors.

Maps published in the aeromagnetic series, and index maps for them, are available from offices of the Geological Survey of Canada and from the appropriate provincial departments if a map was the result of a shared-cost project. Because of the interest taken in new issues, these are placed on sale or order at specified times indicated in notices. Persons and companies can arrange to be placed on mailing lists for these notices.

OTHER MAPS

Maps of several other kinds are useful in connection with certain aspects of prospecting. These include the Mineral Map of Canada which is revised annually and shows the locations of mines and oil fields on a simplified geological base, and the geological, tectonic, glacial, and mineral deposits maps issued in connection with "Geology and Economic Minerals of Canada".* Geological and mineral maps of certain provinces are also available. A series of metallogenic maps and their purpose is explained in Chapters 9 and 11. Some geophysical maps other than aeromagnetic ones are published by the Geological Survey of Canada and the Observatories Branch of the Department of Energy, Mines and Resources. Soil maps published for certain areas by departments of agriculture are useful in connection with some geochemical projects.

Maps outlining the approximate locations of mining claims and other areas held by persons or companies are available for most areas in which prospecting or mining is active. These *claim maps* are prepared, revised, and issued periodically, generally as blueprints or related reproductions, by the provincial departments concerned and the administration of the Yukon and Northwest Territories. They may be obtained from the head offices of these organizations or from local mining–recording offices.

GEOLOGICAL REPORTS

Conventional prospectors, and companies planning advanced projects, rely largely on geological reports and accompanying maps when deciding what to prospect for, what areas to select, where to narrow the search, and also for information on prospects already found and described. Such reports are issued by the Geological Survey of Canada and by most provincial mining departments, the areas or topics being covered with little duplication because so much geological work is required. As reports of several kinds are published by the Geological Survey of Canada the following information will help to explain their characteristics and the uses recommended for them.

The Geological Survey of Canada has for more than one hundred and twenty-five years undertaken basic geological mapping and research. For many years it has also been responsible for much of the detailed mapping in mining camps and other areas of special importance, for the compilation of the results of geological work done by other agencies, for the standardization of geological nomenclature, and, more recently, for the co-ordination of geological research. Many provincial mining departments also perform geological research and publish excellent geological maps and reports, generally on areas or topics not covered by the federal survey at all or not covered by it in detail.

The reports of the Geological Survey of Canada, of which there are several hundred, are of different kinds or 'series'. Before 1935, reports published annually contained the results of several different investigations bound in one volume, and designated Reports of Progress, Annual Reports, or Summary Reports. This practice has been discontinued, publications of the Survey now appearing individually in the 'Preliminary Series', 'Memoir Series', 'Economic Geology Series', and 'Bulletin Series'. The 'Memoir Series' was begun in 1910 and the 'Economic Geology Series' in 1909.

The 'Preliminary Series' consists of preliminary maps and reports, commonly issued before a field project is completed or before all the laboratory and office work is finished. These maps and reports usually cover specific areas; their object is to provide publication of the highlights of the survey results as rapidly as possible; the maps are patterned instead of coloured, to expedite publication; and the reports were formerly mimeographed and are now reproduced by an offset process. These reports, if for an area favourable in a general way for prospecting, provide summarized information on the distribution of formations and on the types of deposits known or likely to be found.

The 'Memoir Series' consists of fairly long reports embodying the full results of the investigation of a map-area or a special field or office project. The accompanying maps are usually coloured. The reports are written primarily for scientists but many parts of them are useful for persons with limited knowledge of geology. Prospectors will find that in most memoirs the introductory parts contain much information on the general characteristics of the area, how to reach it, and how to travel in it. These parts are usually followed by a short introductory account of the geology, written as far as possible in non-technical language. This is followed by detailed descriptions of formations, much of which is too detailed and technical for any but professional

* Economic Geology Report No. 1.

geologists. However, the prospector can ignore these parts entirely or can try to understand as much as possible of the description of a formation or intrusive rock that is especially important for prospecting. He can then proceed to the descriptions of geological structures, which may be very important to him, and to the discussion of mineral deposits.

The 'Economic Geology Series' consists of reports on a particular economic topic covered on a broad regional basis. It begins with 'Geology and Economic Minerals of Canada', and includes comprehensive reports with such titles as 'Lead and Zinc in Canada'. These are based partly on special field and laboratory studies and partly on compilations from local reports. Prospectors will find this series useful for obtaining basic information on the mode of occurrence and distribution of deposits of a particular metal or mineral, as well as for descriptions of many individual districts and deposits.

The 'Bulletin Series' consists of printed reports on special investigations and other matters that warrant publication in final form but that do not belong in the Memoir or Economic Geology Series.

'Reports of Activities' were inaugurated recently to provide the earliest possible release of information on field and laboratory projects that might be useful for the mining or petroleum industries or the general public. Individual issues comprise brief accounts of a number of projects covering a short period.

Some maps or reports that are not being published, at least for the time being, are placed on 'open file' at headquarters in Ottawa and at appropriate branch offices, where they may be inspected. Notification of availability is by postcards similar to those announcing new publications.

The Geological Survey has prepared two kinds of indexes to its publications, in addition to index maps. One kind consists of the following catalogues that list the various types of publications issued during a particular period:

Index of Publications of the Geological Survey of Canada (1845–1958)

Index of Publications of the Geological Survey of Canada (1959–mid-1964)

Index of Publications of the Geological Survey of Canada, issued annually for 1964 and later years.

The other kind consists of indexes to subjects, localities, and authors discussed in different publications, or concerned with them. The earlier indexes in this series are out of print, but the ones for 1927–50 and 1951–59 are available at $13 and $10, respectively.

Publications of the Geological Survey of Canada may be ordered from the Director, Geological Survey of Canada, Ottawa, or from the Queen's Printer, Ottawa. General publications and those for the regions concerned are also available at the branch offices listed in Appendix VII. Government regulations require payment in advance. Remittance should be in Canadian funds, preferably by Postal Money Order payable to the Receiver General of Canada. Postage stamps are not acceptable.

The geological branches of several provincial mining departments issue valuable reports on the geology and mineral deposits of many areas. The annual reports of certain provincial departments contain shorter accounts of areas and deposits. Some of these organizations have published comprehensive indexes to their reports.

AIR PHOTOGRAPHS

Air photographs and *mosaics* made by joining parts of several air photographs have many uses in connection with prospecting and geology, as explained in later chapters. In places where no good topographic map is available one or more photos will usually serve instead. In other places photos provide additional information that could not be included on a map. Use of the expression 'air map' which is often heard is misleading. An air photograph or mosaic is not a map. Topographic maps are commonly made with the help of air photos, but control surveys made on the ground are also necessary; therefore calling such maps air maps or aerial maps is unnecessary and confusing.

The photographing of Canada from the air was begun in 1920, and the whole country has now been covered in at least a preliminary way. Canadian aviators and surveyors were among the first in developing the techniques for this work and for applying the information to topographical mapping, and at the same time Canadian geologists adapted the use of air photographs to their requirements. It is not surprising, therefore, that prospectors were quick to realize that the photographs could in many instances be of great assistance to them.

Types of Air Photographs

Air photographs are of three main types, called *vertical*, *ordinary oblique*, and *trimetrogon*. Any type is usually taken in a series along a carefully controlled line of flight. Recent advances in lenses, films, and papers have resulted in greatly improved photographs. Much geological detail is, however, masked by vegetation except in barren areas; for this reason the best photographs for geological or prospecting use are generally taken in early spring or late autumn. Also, in hilly or mountainous areas, details may be masked by shadows unless the photographs are taken in the middle of the day. In most instances, however, it is necessary to use pictures taken at other times, and these are generally fairly satisfactory. Virtually all prints available are black-and-white. Experiments have been made in the use of colour film for special air photographs, but so far they have not proved particularly useful for geological work or prospecting in Canada, largely because of the trees, moss, or lichen that cover the rocks. Advances in techniques may, however, render colour photography more useful.

Vertical Photographs

Vertical photographs are taken with the camera pointed directly downward, the resulting picture being a plan with little distortion of scale. Each individual exposure overlaps its neighbour by about 60 per cent forward and 15 per cent laterally, so that any specific feature on the ground can be seen on two adjoining photographs, thus permitting it

to be studied stereoscopically. Use of a stereoscope is particularly desirable for photographs of hilly or mountainous areas, because it provides a three-dimensional image that shows the 'depth' of the topography. It is also useful for studying pictures of some fairly flat areas, as there are commonly slight changes in the topography of interest to the prospector or geologist. Some persons prefer to use a stereoscope only in a library or at their headquarters, marking any features of interest; others use a small folding instrument in the field. Stereoscopes can be bought from dealers in engineers' and draughtsmen's supplies, at various sizes and prices. Some stereoscopes magnify the 'depth' of the topography, to assist in studying areas of low relief.

A stereoscope can be used only with vertical photographs taken so that they overlap one another, as this instrument permits one eye to see one photograph, and the other eye to see the corresponding part of another photograph taken when the aircraft had moved to another position along the line of flight. The observer sees the depth or 'relief' of the land-surface photographed. There are two kinds of stereoscopes, one being equipped with mirrors, the other lenses. Some of the former type are made so that they fold, and can be taken to the field. Pocket-size stereoscopes equipped with lenses are available from about $10 upwards, and have the added advantage that they can be carried during the day; their use is, however, more difficult to learn. To use a stereoscope, two photographs, each of which shows the area or feature to be examined, are placed side by side in their proper position with respect to the line of flight. The stereoscope is then set over them in such a position that the central point of each photograph can be seen in the appropriate mirror or lens. A feature such as an island or small outcrop, that appears in each photograph, is selected, and the left and right forefingers are placed over it in the left and right photographs. The observer then places his eyes immediately over the small mirrors, or the lenses. The photographs are then moved slightly to the right and left, and up and down, with the two fingers kept in place, until the two finger-tips appear as one. The fingers are then removed, and a final slight adjustment is made to bring the two images into exact 'stereoscopic fusion', after which the surrounding details will appear in relief. Patience and practice are required before photographs can be 'fused' quickly, and before all details can be recognized. It is recommended that a beginner in the use of air photographs should first learn the techniques that do not require the aid of a stereoscope. Later, he may find it desirable to purchase a stereoscope and to practise its use.

The earlier vertical photographs were generally taken from a height of about 10,000 feet above the ground, with an 8-inch lens, resulting in a scale of about 4 inches to 1 mile; these were printed on 8 × 10 inch paper. Later, as aircraft and cameras were improved, photographs were taken from 15,000 to 20,000 feet, resulting in scales of about 2 inches to 1 mile. These photographs were printed on 10 × 10 inch paper. Since 1950 the trend has been towards ultra-high-altitude photography at 30,000 to 35,000 feet, resulting in scales of about 1 inch to 1 mile. For special purposes, such as detailed work near mining camps, vertical

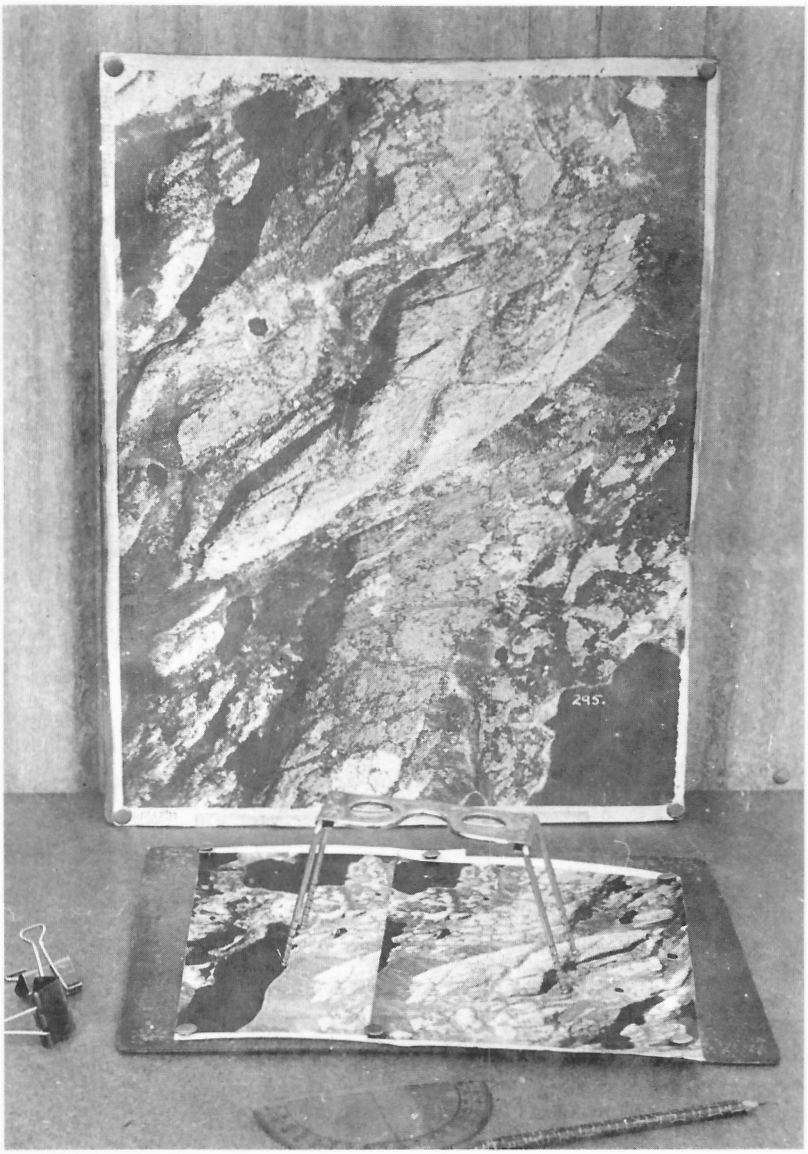

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Plate 54. A small stereoscope and a pair of vertical air photographs arranged for stereoscopic inspection. An enlarged vertical air photograph of part of the same area is shown in background.

photographs have been taken from much lower heights, resulting in greater detail and larger scales. Some areas have been re-flown several times, with the result that photographs of different scales and qualities are available.

Vertical photographs are usually the most satisfactory type, and are now available for virtually all of Canada. Most vertical photographs are taken along flight lines as nearly east and west as possible, one flight travelling in one direction, and the adjoining one travelling in the opposite direction. In special cases, however, photographs may have any orientation. The approximate direction of north is usually determined by selecting some feature such as a lake, road, or stream shown on both the photograph and on a map, and from these the photograph is oriented so that this

feature corresponds in both photograph and map. Occasionally a photograph shows a surveyed line that has been cut through timber, in which case a more precise orientation can be made as soon as the map has revealed whether or not the photograph was being viewed 'upside down'.

The scale of a photograph, or a series of them, varies to some extent because of distortion in the lens of the camera, tilt of the aircraft, unevenness in the line of flight, and variations in the surface being photographed. These changes in scale are corrected in making accurate maps from air photographs, but they may be ignored so far as prospecting is concerned. The date of photography, the altitude from which the photograph was taken, the lens number, and the approximate scale are usually given on the back of a photograph. If this is not done, two points that appear on a map can be selected, and their distances on the photograph and on the map can be measured and compared. Another method is to measure on the ground the distance between two points that appear on a photograph. If the approximate elevation of the ground is known, the approximate scale can be determined by subtracting the ground elevation from the altitude and dividing by the lens number.

Ordinary Oblique Photographs

Ordinary oblique photographs were first taken from the nose of a flying boat, with the camera pointed slightly downward and at about 45 degrees to the direction of flight. Three exposures were taken from any given position of the aircraft, and were designated left, centre, and right 'obliques'. When the more modern types of cabin aircraft superseded flying boats, triple cameras were developed and mounted so that they took one 'oblique' looking backward along the line of flight, and left and right 'obliques' directed backward at about 45 degrees to the line of flight. All oblique views show perspective with gradual loss of detail towards the horizon. They are easy for beginners to interpret because they provide a more natural view than do vertical photographs, but distances are difficult to estimate. Photographs of this kind are now considered obsolete for mapping purposes, and most areas originally covered in this way have been re-flown for vertical photography, but some oblique photos illustrate certain geological features better than do vertical ones.

Trimetrogon Photographs

Trimetrogon photography, begun during the last war, is a combination of vertical and oblique systems, with one view directly downward, and left and right 'side obliques' at right angles to the line of flight. Generally these are taken from about 20,000 feet above the ground, with a 6-inch lens, the vertical picture having a scale of about 3,000 feet to 1 inch.

Trimetrogon photography can be done much more quickly and cheaply than vertical photography, and is quite suitable for making topographic maps of large areas. It is not so suitable for detailed work because of the scale and the lack of stereoscopic coverage. Trimetrogon photographs do have one advantage for geological interpretation in that their broad coverage may illustrate large features such as folds, that might not be detected on vertical photographs. Because they are made with more modern equipment and at great height, they are better for this purpose than the old obliques.

Enlargements

Enlarged vertical photographs are very helpful for detailed geological work and special prospecting projects. If they are enlarged too much, however, the features become blurred. For many purposes it has been found that enlarging to scales of 400 or 500 feet to an inch is satisfactory.

Mosaics

To provide a view of an area larger than that of a single vertical photograph, several adjoining photographs may be matched together and mounted on cardboard, or photographed to permit reproduction. Such assemblages are known as 'uncontrolled and uncorrected mosaics' because there is a certain amount of distortion. They provide useful views of an area such as a group of mineral claims, but are not strictly accurate as to positions and distances. Large prints of mosaics are now available for about two-thirds of Canada, at 4 to 12 miles to 1 inch. For other areas, mining companies sometimes arrange to have a commercial organization take special pictures and compile a mosaic. Some companies buy copies of available photographs and make their own mosaics.

How to Consult or Obtain Air Photographs

The greater part of the air photography of Canada has been done by the Royal Canadian Air Force or by commercial flying companies working on contracts for departments of the federal government. Much photography has been done for provincial governments also, as well as for private mining, oil, and logging companies, but in the case of the last three, prints are not usually available to the public.

Services of the Federal Government

The Department of Energy, Mines and Resources maintains the National Air Photographic Library at Ottawa. Here is kept one print of each photograph taken for the federal government, totalling more than 3,000,000 prints. Photographs for any area can be studied by visitors to the library, but they cannot be lent. Orders for prints are taken and forwarded. Photographs are designated by serial numbers, usually composed of a flight number and a number indicating the position of the photograph in the flight series. The direction of an oblique or trimetrogon photograph is also indicated in the serial description.

A map showing the type of photography available for any part of Canada may be obtained from the library free of charge. Ordinary prints are obtainable at 60 cents each, and enlargements cost as much as $13.00 for the largest size, which is 40 by 60 inches. Copies of mosaics cost about the same as an enlargement of corresponding size.

Prints and mosaics may be ordered from the library in person or by mail, by enclosing a copy of the best available map, or a tracing therefrom, on which the exact area for which photographs are desired is outlined. The following information should be given:

(1) The scale desired, if vertical photographs are requested. For some areas, photographs are available on scales of about 1, 2, and 4 inches to a mile, and for a few areas, larger scales are available.

(2) Whether matte or glossy prints are desired. The former are preferable for marking with a pen or pencil, but glossy prints may give sharper detail.

(3) Whether stereoscopic coverage is desired. If not, only half as many prints are necessary.

The library will advise the cost, and place an order on receipt of payment in advance, which should be by money order payable to Receiver General of Canada.

Services of Provincial Governments

In British Columbia, Alberta, Ontario, and New Brunswick, photographs covering much of these provinces can be inspected at, and in some instances bought from, provincial government offices. Information can be obtained from the following:

1. Air Photo Library, Department of Lands and Forests, Victoria, B.C.
2. Technical Director, Department of Lands and Forests, Edmonton, Alta.
3. Surveyor General, Department of Lands and Forests, Toronto, Ont.
4. Director of Photogrammetry, New Brunswick Department of Lands and Mines, Fredericton, N.B.

Other provincial departments have given photos taken for them to the National Air Photographic Library, to whom enquiries may be sent.

Suggestions for Additional Reading

Bostock, H.S.
1968: Catalogue of selected air photographs; *Geol. Surv. Can.*, Paper 68-21.

How to order an air photograph; National Air Photo Library, Surveys and Mapping Branch, Department of Energy, Mines and Resources.

9

conventional methods of prospecting

Conventional prospecting is essentially the searching of outcrops and gravels for valuable mineral deposits including placers, by persons lacking advanced training in a specialty such as geology, geophysics, or mining engineering. When searching for certain kinds of deposits conventional prospectors now commonly use fairly simple instruments such as a Geiger counter, a fluorescent lamp, or a dip needle. These instruments are discussed in chapters on advanced prospecting because they can be treated most logically there, but they are also applicable to competent conventional prospecting. Conventional prospectors should also be able to make practical geological observations for themselves and to effectively use information obtained from geological maps and reports. For these reasons there are no absolute distinctions between conventional prospecting and the advanced methods described in later chapters, but the categories are fairly distinct.

Although based largely on scientific principles, conventional prospecting is an art or craft rather than a precise science; it includes a large element of luck and much scope for individual preferences, hunches, craftsmanship, and experience. There are, therefore, no hard and fast methods for this kind of prospecting; much depends upon the person concerned, the metal or mineral sought, and the nature of the area being investigated.

All that can be attempted in the following discussion is to describe what appear to the writer to be logical procedures for choosing a field for prospecting and for conducting the search. An attempt has been made to strike an average, so that the discussion is not confined to the operations of prospectors who have little technical knowledge, or to those most experienced and best informed; moreover, average conditions were envisioned, with the assumption that the reader would realize that modifications would be required to suit particular circumstances. The subject is treated as though the reader intends to work independently and therefore to make his own decisions, but much of what is said applies also to supervised prospecting schemes that include conventional prospectors.

SELECTION OF REGION

This problem naturally does not arise if the prospector intends to work only his home area or an area where he is stationed temporarily. In such circumstances, he should obtain geological literature on the region, and from this and his own observations he can learn the kinds of mineral occurrences known or likely to be found. Then, if the region is at all favourable, he would proceed in the manner described later. If the field is restricted in this way, there is of course not as much scope for the prospector. The home area, nevertheless, may still warrant examination by resident prospectors unless it has already been searched thoroughly. Because accessible areas have been prospected already any chances remaining for conventional prospecting will favour those who have acquired most skill and proficiency.

Most full-time prospectors are prepared to make special trips lasting from a few weeks to an entire season. Such trips should be undertaken only after a great deal of preliminary study and planning, perhaps during the winter, unless the prospector is very experienced and has definite areas in mind as a result of previous investigations, or unless he decides to join a rush to the scene of a newly reported discovery. The selection of a region is usually based on one or more of the following considerations:

(1) A particular objective, such as the search for deposits of a particular metal or mineral.

(2) General suitability of a region, i.e., one believed to be favourable for prospecting, but not specifically for any one mineral or metal.

(3) A reported important discovery in a new region.

(4) Accessibility of the region.

(5) Personal considerations, such as the prospector's financial resources, physique, experience, preference, and amount of time available.

(1) *Deciding on a particular objective.* Many prospectors concentrate for the time being on a particular metal because it is in demand and 'in fashion'. If so, this is likely to be the main factor in selecting a scene of operations. For example, gold has not attracted many prospectors during the last few years because its price remains fixed while wages and the other costs of mine operation are steadily increasing. A gold discovery would have to be exceptionally good, therefore, to interest capital at present. On the other hand, much interest was taken some years ago in prospecting for uranium because it had a guaranteed market (under certain conditions) until 1962, and because of a great deal of spectacular publicity. During the last few years much emphasis has been on good deposits of nickel, copper, or molybdenum. Instead of a single objective it may be wiser to concentrate on two or three kinds of deposits that might be found in a particular area and in any case a prospector should always be alert for any unexpected occurrences. Further information on the demands and prospecting possibilities of many metals and minerals is contained in Chapter 15. Prices and demands for most metals and minerals are variable; therefore the prospector must allow for the possibility of changes having taken place since the last report was prepared, and should check prices for the six months or so preceding the commencement of field work.

Every prospector should subscribe to, or in any event read, at least one of the mining newspapers or magazines to keep informed on up-to-date quotations on prices of metals, trends in the demand for different metals, and new discoveries and districts. When the choice has been narrowed down to a few metals it is advisable to study government publications such as the reviews on the metals and minerals produced in Canada annually by the Department of Energy, Mines and Resources, or reports on particular metals published in the Economic Geology and Preliminary Series of the Geological Survey of Canada, or reports on particular metals issued by some provincial departments. A point worth considering is that interest in particular kinds of deposits often goes through cycles. During a period of lessened interest in a particular metal or type of deposit, prospecting may be easier because other prospectors are not competing. It may, however, be more difficult to obtain backing for such prospecting or to interest companies in discoveries.

After careful consideration, a particular metal may be chosen as the main objective, but the prospector should always plan to be on the alert for occurrences of other kinds. Having made such a decision, the prospector should read as much as possible on the mode of occurrence and demand for that metal, and on its uses, and also reports on some of the main areas where deposits have been found in Canada or elsewhere. If he can visit a mining library it will facilitate obtaining such information without his having to buy a number of publications that he may not use again, and it will also permit study of publications that are out of print. After reading accounts of some of the main districts, he can consult general indexes and so find references to many other occurrences of the chosen substance. He may learn that definite regions or belts are recognized as being favourable in a general way for a particular metal. In this connection the general metallogenic maps and ones for several individual metals published by the Geological Survey of Canada may be useful. Metallogenic maps show known occurrences or groups of occurrences of metals, in relation to regional geography and tectonics. Various classes of occurrences, such as veins, pegmatites, stratiform deposits, etc., are commonly differentiated.

The prospector next has to decide whether to select a region where important discoveries of the kind he seeks have been found, or one where at least minor occurrences are known, or one that is merely favourable in a general way. The old saying that "the surest place to find a mine is where one has been found before" has much to recommend it, although it is only partly true, but such districts are usually staked or, if they are abandoned, ordinary prospecting has probably been fairly thorough, so that the chances are mainly for special methods of prospecting. The next choice may be a less popular area where the metal has been found, in which there may be better chances for ordinary prospecting and for finding open ground. Another choice is a district where the metal has not previously been reported but where the geological conditions are reasonably similar to those of districts containing important deposits. Or, a district may be chosen on the basis of an independent theory or hunch.

When the choice is reduced to a few areas, it is advisable to learn how completely these are staked. This can sometimes be learned from articles in the press or from local prospectors who know the situation; otherwise, claim maps may be ordered from the government department responsible, as explained elsewhere. These maps usually cover one township, or larger areas where a region is not divided into townships. In this way, it may be decided that a particular region is too completely staked to be desirable. In any case, it is advisable also to consult the Mining Recorder for the district to learn about the most recent staking.

(2) *Selection based on general suitability.* It is by no means necessary to have one particular metal or mineral in mind as a goal for prospecting. Particularly in the case of metals, many districts contain several metals in payable amounts. Many important mining camps have certain geological features in common, although no two are alike in all respects. A field for prospecting, therefore, may be chosen simply because it is known to have some of the geological conditions that are commonly associated with mineral deposits, although no deposits have yet been found or reported. Examples of such conditions are greenstone belts in the Canadian Shield, and areas containing prominent faults or fracture systems, contact zones of stocks and batholiths, or intrusive rocks or sedimentary or volcanic formations of the same kind or age as those in which mineral deposits have been found in other areas. Concentrations of metals or minerals in workable quantities are formed by a combination of unusual geological conditions; therefore they are generally in areas where the geological conditions are unusually complex.

(3) *New discoveries.* Prospectors and others often rush to areas where new discoveries are reported. This is understandable, but unless one "gets in on the ground floor" he will probably find that the area is fully staked for a long way around the discovery. Rushes generally result in staking bees participated in by persons who are merely speculators who hope to sell their claims promptly, as well as by prospectors who feel that they have to stake first and investigate afterwards for fear there will be no open ground left. Latecomers have to prospect on the fringes of the district or wait for claims to lapse. These are not always disadvantages, because discoveries may be made miles away from the original one, or on hurriedly prospected claims that are abandoned. However, careful consideration should be given before joining the more popular rushes; because so many persons participate, transportation and other services may be taxed to the limit, and many of the early reports may have been exaggerated.

(4) *Accessibility.* The advantages and disadvantages of accessible and remote regions should be carefully weighed. Areas near settlements and good transportation facilities are easier to reach; require less expenditure on travel, supplies, and outfit; are usually better covered by maps and reports; and permit rapid dispatch of samples and return of assay results. In an easily accessible area it is

easier to induce companies to send a representative to examine a discovery; the cost of exploring a deposit is much less; and, most important of all, a deposit does not have to be as large or as rich to justify mining as it would in a place where transportation costs were higher or where special transportation facilities would have to be provided. On the other hand, most accessible areas have been prospected already, either very thoroughly or to a considerable degree. The possibilities in these areas are, therefore, mainly for special methods of prospecting; for ordinary methods the opportunities are mainly in the off chance of finding something that was overlooked, or in changed circumstances that make some metal or mineral valuable today, whereas it was not given attention formerly, or that have made deposits of lower grade more attractive.

The farther the prospector goes from established districts and easy transportation routes, the greater will be his chances of making a discovery by conventional methods, but he will have to overcome more problems. Apart from problems of travel and work in remote places, testing of a discovery will have to indicate higher grades than if it were located more favourably.

Accessibility may influence the selection of a prospecting field in other ways. If a new highway or railway is to be built or has recently been built it makes the region along and near it more attractive for prospecting, and easier for the development of discoveries. New highways and railways generally provide additional exposures in rock-cuts.

(5) *Personal considerations.* A prospector's own finances or the extent of his backing generally influences the selection of a region. Remote places may be beyond his means or his time. Also, his physique may not be suitable for very remote or mountainous places, or he may not have sufficient experience in travelling and living in such places. Finally, there is the question of preference; a man may prefer fairly settled or fairly remote places, or he may not like canoeing or flying or some other feature of prospecting in a particular region.

AFTER DECIDING ON A REGION

After the region has been selected the prospector should gather as much information as possible about the area to be visited. To do this he can consult lists of publications to learn what geological maps and reports are available from the Geological Survey of Canada or from the appropriate provincial mining department if the region is in a province, or he may write to the government agency concerned for information, specifying the region clearly. If geological maps do not suffice, he can usually obtain federal or provincial topographic maps from the addresses listed elsewhere in this book. The prospector should study maps and reports carefully, if possible before going to the field. It is advisable to make notes regarding pertinent information contained in publications that are out of print or that are not being taken to the field for other reasons. Most geological reports contain information on methods of travel to the area and in it, routes, the degree of bedrock exposure, recommendations for prospecting, and other general data besides the description of the geology and known mineral deposits. By preliminary planning of this kind it is possible to judge what equipment and supplies will be required, to decide what part of the area to investigate first, and to make a tentative plan of operation.

If possible, air photographs should be studied before the prospector goes to the field. They are particularly useful for areas for which geological maps and reports are not available, but are also commonly helpful in providing supplementary information when such maps and reports are obtainable. If it is possible to visit the National Air Photographic Library at Ottawa or one of the collections kept by certain provincial agencies, the photographs available for the region may be studied, and notes or tracings may be made of data that may be of interest. Otherwise, copies may be ordered through the Air Photographic Library, as explained in an earlier chapter. Many prospectors also make good use of air photographs while in the field, as well as in preliminary planning. These field uses are explained in a later section of this chapter.

Unless one is familiar with the staking regulations for the province or territory concerned, he should obtain a copy of the appropriate regulations and study it carefully. He must also have a staking licence or its equivalent. Copies of regulations can be obtained by writing to or calling at the head office of the provincial department concerned*, or at local recording offices; licences may also be purchased from the Recorders.

On the way to the selected area, the prospector will often have an opportunity to visit the office of a resident government geologist, mining recorder, or other official who can give him information about the area, as well as about the amount of staking and the number of prospectors likely to be there; the latest claim maps may also be obtained. The newcomer may also meet other prospectors willing to give him information, and scouts or other representatives of mining companies that he may later wish to interest in a discovery. In this connection, a little advice to beginners may be useful. Prospecting and other branches of the mining industry are highly competitive, and those engaged in it are seldom given to broadcasting news of their discoveries. It is therefore not advisable to ask a man directly where he is going, where he has been, what he has found, or his opinion of someone else's discovery or property; let him volunteer any information he cares to give. It is advisable, also, to be on guard against over-enthusiastic reports; prospectors have to be optimists, but sometimes their enthusiasm gets the better of them. Another hazard is the occasional instance of specimens from an entirely different region being shown, or of wrong directions being given, either as a practical joke or with a deliberate intent to mislead.

While he is in the town from which the final stage of the journey is to commence, the prospector should make defi-

* For the Yukon and Northwest Territories, letters may be addressed to: Chief, Resource Management Division, Department of Indian Affairs and Northern Development.

nite arrangements for the holding or forwarding of mail; the periodical shipment of supplies, if necessary; and definite arrangements for being picked up, if he is travelling by air. If there is an assay office in the town, he may wish to arrange for the assaying of samples sent from the field, and for the forwarding of assay reports.

WORK IN THE CHOSEN REGION

Before reaching the area, the prospector will probably have decided whether circumstances will permit him to work for some time from a fairly permanent base, perhaps making short, light trips away from it, or whether he will have to make frequent moves with his entire outfit. In the former case, he will probably spend a little time establishing a base.

Next, he will probably try to become familiar with some of the rocks and known mineral occurrences in the vicinity. He will already have done this to some extent en route, for even if he travelled by air he would have made observations, and might have arranged a reconnaissance by air instead of going directly to his first camping-place. If the geology has been mapped, time will be well spent in examining outcrops of different formations and types of rock, and in comparing them with the geologist's descriptions. If the geology has not been mapped, the prospector will probably make a reconnaissance by canoe or on foot to get an idea of the rocks and structures present, and so to plan his work. At all times he should take mental note or make a sketch of any prominent landmarks to help keep his directions. If abandoned mineral deposits are reported in the vicinity, he will probably visit them to learn about them at first hand. Such examinations add much to a prospector's general knowledge of the nature of mineral deposits, helping to supplement what has been learned from handling specimens in a course or at home. His ability to judge a discovery will be improved if he considers whether abandoned ones were worked out, too small, too low-grade, too 'spotty', etc. It should always be borne in mind that abandoned underground workings may be dangerous to enter, especially for inexperienced persons. A prospector may also be able to visit prospects that are undergoing testing, but permission to go underground at producing mines is usually difficult to obtain because of safety regulations.

The manner of prospecting is determined by personal preference and experience. In general, the need nowadays is for patient, detailed searching, particularly if the region concerned has previously been prospected. A diary, including particulars of occurrences found and samples taken, should always be kept. Also, much depends on the local geological conditions, and on the kind of deposit sought or that may occur. The prospector has probably made up his mind to investigate first some particular formation, fault, contact zone, or other feature whose existence is known or surmised. He would then proceed to cover this local area more or less systematically, by closely spaced traverse lines if outcrops seem scarce (*see* Fig. 19), or by going from outcrop to outcrop if these are visible, and in places scraping away moss or shallow overburden if necessary. In places where outcrops are scarce it is advisable to watch for fragments of rock lodged in the roots of overturned trees, and for angular blocks of rock brought to the surface by frost action. Both are quite unlike the rounded shapes of pebbles and boulders that probably came from afar and bear little or no relation to the underlying bedrock. Figure 18 illustrates traverses done on three consecutive days in a locality where outcrops were scarce. The prospector left his canoe at A and walked north to B, prospecting as he went, to investigate the contact zone of a body of granite shown on a geological map. He made zig-zag traverses well into the granite and away from it, and found a few outcrops but no signs of mineral occurrences. Near the end of the day he had reached point C, so he estimated the compass bearing that would get him back to his canoe. On his way back to A he crossed a gully at D and found outcrops that showed signs of shearing, so he thought this might represent a zone worth intensive prospecting. He blazed his way back to A so that he could retrace his steps. Having done so on the following day, he made closely spaced zig-zag traverses all day, and then returned to his canoe at A. The next day he left his canoe at E and walked back to D on an estimated bearing. He then traversed the western extension of the zone. Thus in three days he not only traversed in detail two possibly favourable zones, but also made several traverses in different parts of the intervening territory, and examined the shoreline from A to

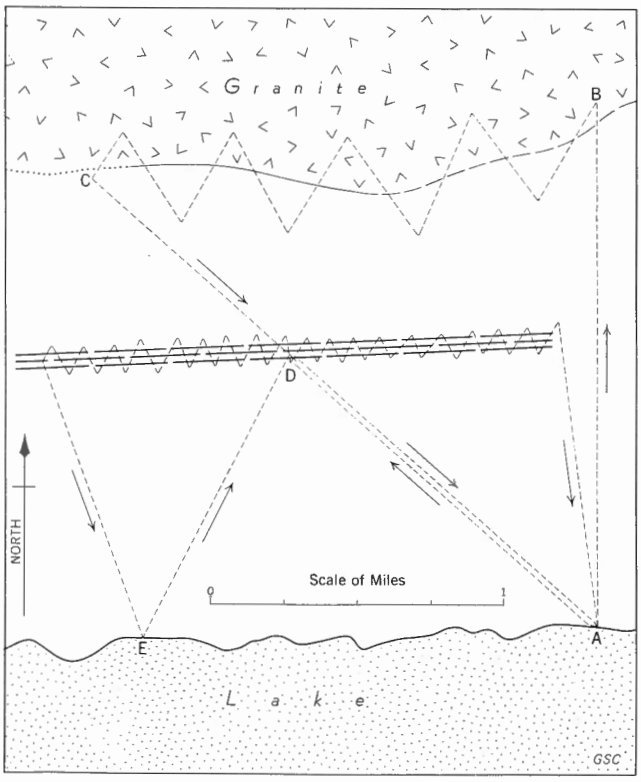
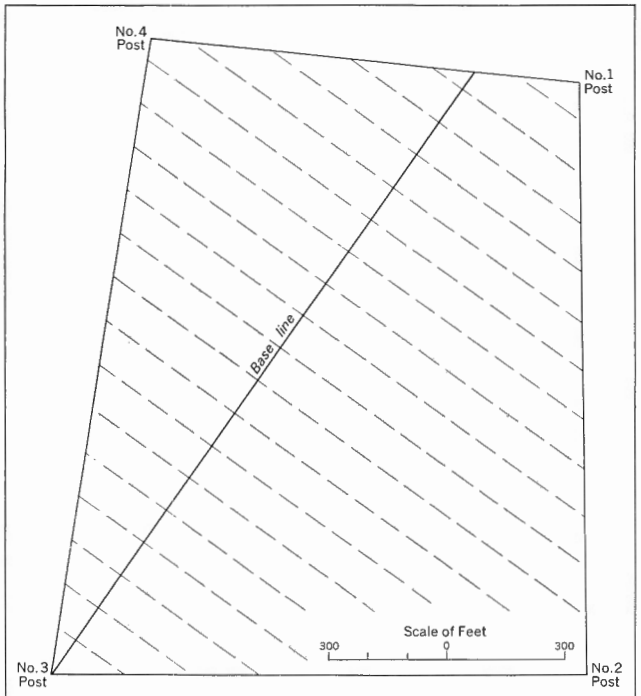


Figure 18. An example of prospecting traverses.

E. If outcrops were observed during any of these traverses, the routes would be altered so that they could be examined.

If clues for selection of a particular area are lacking, or if the prospector is of less methodical habits, he may simply work his way through the country in any manner he chooses. Almost all agree that fairly systematic coverage or 'traversing' of at least the more favourable parts of the area gives best results in the long run, although too prolonged or too stubborn adherence to one theory or one set of conditions is often unwise. Whether to go from outcrop to outcrop, or along ridges, or to run lines with a compass, is largely a matter of topography and visibility.

A third circumstance arises when prospecting claims that have already been staked. Then it is usual to cover them fairly thoroughly and methodically, paying greatest attention to what are thought to be the more favourable rocks or structures. Prospecting of claims is often done along lines 100 to 500 feet apart, in a direction more or less across the prevailing strike of formations or structures (*see* Fig. 19). The lines are directed by using a compass or by sighting along pickets, as explained in Chapter 14, and they may be blazed and cleared if necessary. Geological observations are often made along such lines, if the prospector has sufficient training or if an organized group includes geological workers; the results would then be plotted to make a geological map. In some types of work, readings with special instruments such as Geiger counters or dip needles



In this instance a base line was surveyed by tape and compass, in a direction approximately parallel to the trend of formations or structures. Cross-lines were then run at 100-foot intervals, either by compass and pacing, or picket lines and pacing. If there were several claims in a group the lines would probably cross several claims or all of them. If one side of the claim was nearly parallel to the trend, or if there was no definite trend, a claim line might be used as a base line.

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Figure 19. Lines surveyed for detailed prospecting of a claim.

are taken along the lines. The same lines may also serve if more advanced work in the form of geological, geophysical, or geochemical surveys is undertaken (*see* Chapters 11, 12, and 13). In detailed prospecting of certain areas in proved mining camps, it may be desirable to do extensive stripping or trenching across the strike of particularly favourable formations or structures if the overburden is not too deep. Whatever method is adopted, it is important to keep notes and to mark on a map, if possible, the exact locations of points where notes or samples were taken.

In most areas it is possible to eliminate certain sections as being less favourable and to concentrate on others. It must be remembered, however, that such eliminations are not certainties, but merely part of a system to permit prospecting to be done on what seems to be the most favourable ground. Sections may be eliminated because they contain few rocks exposures, but many important deposits occur in places where there are few or no exposures. This is sometimes because the deposits occur in fractured or faulted rocks that weather readily, or because the minerals in the deposit are of a kind that decompose easily; both conditions tend to produce depressions, which are natural places for overburden to accumulate. Low-lying areas are therefore favourable places for prospecting by ordinary methods, if the overburden is not too deep, and should not be disregarded. Large sections underlain by uniform granitic and gneissic rocks are usually considered to be among the least favourable, but deposits do occur in such environments, so they cannot be ruled out entirely; in particular it should be remembered that such sections may not be as uniform as they appear from the results of preliminary prospecting or on geological maps made by widely spaced traversing.

One of the first principles a prospector has to learn is that although mineral occurrences are fairly common, deposits that will pay to mine are much scarcer. This fact should not discourage prospecting, but it is necessary for beginners to learn not to get excited about every occurrence they find. Instead, they should keep looking for fairly large occurrences or for small exposures that may prove to be more extensive under overburden or at greater depth.

The question of what to look for when prospecting is one of the most difficult matters to discuss, because so much depends on the kind of deposit sought, on local conditions, and on the prospector's individuality. All that is attempted here is to discuss briefly some of the principal clues and methods that have proved useful, particularly in the search for metalliferous deposits. It should be emphasized that all the guides mentioned probably would not be present in connection with any one deposit, although two or more might occur together.

Veins. Veins constitute one of the commonest classes of mineral occurrences and deposits. They are among the easiest to recognize, particularly if they are quartz veins, because the light colour of quartz generally contrasts with the wall-rock, and because the resistance of quartz to ero-

sion often produces bold outcrops. The term 'vein' is used in this connection to include not only regular veins, but also stringers, stockworks, and irregular masses of quartz or other vein minerals.

Many veins and other bodies of quartz do not contain valuable minerals; quartz of this kind is often called 'bull quartz'. Most quartz veins contain little, if any, of the transparent variety typical of quartz crystals; as a rule veins consist of milky white quartz, although bluish, blackish (smoky), and pinkish varieties are not unusual. Barren quartz is commonly glassy and it may have a bluish tinge, but these are not always reliable characteristics for distinguishing worthless quartz. Many quartz veins, however, are not barren, but contain gold, sulphides, or minerals like scheelite, which may be present in either unimportant or commercial quantities.

There are also many veins in which quartz is absent or only a minor constituent. Veins composed of one or more metallic minerals only are rare, but they do occur, as in the case of native silver. Usually, however, gangue minerals form most or all of the vein, and, if quartz is not the main constituent, calcite or other carbonate minerals are likely to be the chief components.

All veins, no matter how small or seemingly barren, should be examined and followed closely, because small veins may lead to larger ones, and barren parts may lead to sections containing valuable minerals.

Pegmatites. Dykes or irregular bodies of pegmatite are among the most easily found occurrences, because they are usually light in colour and resistant to erosion. Most pegmatitic occurrences are unimportant, but all are worthy of scrutiny because some contain valuable minerals in workable amounts.

Favourable Structures. A prospector should watch for signs of shearing, fracturing, or faulting because, even if such structures do not contain veins or other deposits at the place where they are first encountered, they may do so at some place nearby.

Discovery of Valuable Minerals in Place. Valuable minerals may be exposed in recognizable form at the surface of outcrops, or in fragments of rocks broken off by the prospector or lying nearby, or they may be exposed in excavations such as road or railway rock-cuts. This is particularly true of resistant minerals like gold that do not erode or decompose readily, but even these minerals may be in such small grains that they are difficult to detect. Many other minerals alter readily by weathering at or near the surface, and are only found by indirect evidence such as mineral associations, or secondary minerals, as is explained later. Therefore, although important amounts of a valuable mineral may at times occur fairly conspicuously, as a rule such deposits are found as a result of careful investigation of the vicinity where a little of the mineral has been found, or where some indirect clue has been noted. Many of the more valuable minerals are heavy; therefore a prospector should suspect any material that seems heavier than normal rock, even if he cannot identify valuable minerals in it. He might pan such material, or send samples for assaying.

Mineral Associations. At the surface, many valuable minerals are altered beyond recognition or are completely dissolved and carried away from outcrops. In such cases a more resistant mineral that is commonly associated with the one sought may provide a clue for its presence beneath the weathered part of the deposit.

Mineral associations have already been mentioned in connection with quartz veins. Here the quartz, although generally valueless itself, is a conspicuous and resistant mineral with which valuable minerals are often associated. There are also many less obvious associations, such as gold with pyrite and other sulphide minerals, nickel with pyrrhotite, silver with lead and zinc minerals. A prospector should try to learn as much as possible of these associations. If sizable bodies containing minerals that might indicate the presence of more important ones are found, samples should be panned or sent for assay.

Gossans, Mineral Stains, etc. Many metalliferous minerals alter fairly readily in the presence of moisture. This matter is discussed more fully in the section on mineral deposits, but it is mentioned here because of its importance as a clue in prospecting. In some instances, metals or other elements are dissolved and carried in solution to deeper parts of the deposit or to an entirely different place. In other instances, new minerals are formed in the outcrop of the deposit. These are generally called secondary or supergene minerals because they are produced by alteration of the first-formed or 'primary' minerals. Some of the original minerals may be entirely changed to supergene products in the near-surface part of the deposit or, more rarely, at depths of 100 feet or more below the surface. On the other hand, the secondary minerals may form only a thin crust or 'bloom' on the surface of primary minerals, or they may have migrated a little way to form a stain on the surface of other parts of the deposit, on nearby rocks, in overburden, or to line cracks and cavities near the surface of the deposit. Supergene minerals occurring in any of these ways are often important indications to the prospector, because they may be the only clue to a nearby primary deposit, and because many secondary minerals are bright in colour and hence easily recognized. It must be emphasized, however, that the presence of a very small amount of some primary minerals may produce widespread staining. It should also be remembered that lichens and other growths on rocks may produce coloured encrustations that at first glance may resemble mineral stains.

The most common supergene minerals in outcrops are limonite and other secondary iron compounds, because pyrite and other iron minerals are common primary constituents of mineral occurrences. The primary iron minerals oxidize to form rusty outcroppings ranging in colour from yellow to chocolate brown or red. These rusty outcrops are generally called *gossans*, from a word used by early Cornish miners to describe them. Typical gossans consist of limonite and a cellular mass of quartz that resisted alteration,

but the term is used more loosely to describe any rusty outcrops. Unfortunately, many gossans are unimportant either because they resulted from insignificant amounts of iron sulphide minerals, or because the only primary mineral is pyrite, which is in demand only under special circumstances. However, other gossans may lead to useful deposits containing hematite, or valuable sulphide minerals, or minerals like gold that are commonly associated with sulphides. It should be noted that magnetite does not oxidize easily, except when associated with sulphides; therefore magnetite deposits may not be marked by gossans.

Many other important primary minerals alter to characteristic secondary minerals that are very useful as clues for prospecting. The principal ones are as follows. Copper produces malachite and azurite, which have characteristic green and blue colours, the former being similar to 'verdigris' and the latter to 'bluestone'. Nickel–arsenide minerals produce an apple-green mineral or stain. Cobalt–arsenide minerals produce a characteristic pink to red 'cobalt bloom'. Molybdenite alters to a pale yellow mineral generally called molybdenum stain. Manganese minerals produce black supergene minerals that are often sooty or iridescent; this material may migrate a short distance from the deposit and form a black mass called 'wad' that may cement soil or gravel. Minerals containing uranium alter readily, generally to vivid yellow, orange, or green minerals. Many different yellow or orange supergene uranium minerals have been named and described, but unless they occur in large quantities it is usually sufficient to refer to them collectively as 'uranium stain'. Minerals containing lead or zinc may alter to various oxide and carbonate compounds; some of these are white, and others are of several colours; as a rule, they are not as useful guides as those mentioned previously. Many of the stains and supergene deposits are soluble in water and are removed from the surface by heavy rain or melting snow; hence at such places the surface rock must be broken to find them.

Although many gossans and other secondary deposits are unimportant, all merit investigation. This may consist of trying to pick or blast down to the primary minerals, or of panning the altered material in the hope of finding traces of the heavier, primary minerals, or of sending samples for assay.

Wall-rock Alteration. The rock enclosing many mineral deposits is altered by the introduction of solutions that preceded or accompanied the deposition of the ore minerals. These solutions commonly react with the original rock-forming minerals to form new mineral compounds, or they may produce disseminated grains or masses of some of the same minerals that occur in the deposit itself. The altered zones may extend only a few inches from the deposit or many feet. The most common alteration minerals are white mica, chlorite, quartz or other compounds of silica, calcite or other carbonate compounds, and disseminated pyrite or hematite. By studying alteration zones beside known mineral deposits a prospector can learn to recognize the commoner types, and he should be constantly on tne alert for similar occurrences of altered rocks, since this knowledge might stand him in good stead if the altered rocks around a deposit outcropped and the deposit itself was not exposed or was difficult to recognize.

Tracing Float. Fragments from a mineral deposit are often transported by glaciers, streams, floods, frost action, or gravity. If carried a long way, almost all are rounded, but if they have not travelled far most are fairly angular. The term *float* is usually restricted to angular material from a mineral deposit, the name alluding to its having 'floated' away from its place of origin. Pieces of float may be recognized in stream beds or on the surface of the land, particularly along hillsides. It may then be possible to trace float to its source by finding additional pieces. In general, the larger and more angular the pieces are, the closer they are to the source. In some cases it is possible to work up a stream and gradually eliminate tributaries that do not carry float of the particular type being sought, thereby narrowing the area of the possible source. Or, if one works along a hillside, the distribution of float may be found to occur in a roughly triangular pattern with the apex at the deposit. In places where outcrops are scarce it is useful to look for float in depressions caused by the blowing down of trees, and among the roots of such trees.

Tracing float in glacial drift is an important and usually complicated kind of advanced prospecting and is discussed in Chapter 11, but experienced conventional prospectors might find some of the subjects mentioned there useful to them.

Panning. In addition to its use in prospecting for placer deposits and testing them, panning is often very useful in 'hard-rock' prospecting. Several authorities have recently expressed the opinion that prospectors are not making sufficient use of the pan when searching for or testing lode deposits. Very fine float invisible under ordinary circumstances may be panned from the beds of streams or from gravels or soils. Very widely scattered grains may be evenly dispersed through glacial drift, but otherwise the discovery of float by panning is a useful aid in tracking down a deposit by the same process of elimination described above for tracing coarser float.

Another important use of the pan is in testing samples from gossans or other outcroppings, as a means of detecting heavy valuable minerals, and of estimating their quantity. This may save the time and expense of obtaining preliminary assays. Samples may be tested nearby if water is available, or at camp. The samples are crushed in a mortar, or, if no mortar is available, they may be hammered on a hard flat surface such as the side of an axe. To prevent loss of particles, the sample can be kept in a canvas bag while being hammered. The sample should be ground finely enough to free small grains of minerals. This is best done by periodically screening the sample and then continuing to crush the material that will not pass through the screen. Screens with 60 or 80 meshes to the inch are recommended, particularly if minerals are likely to be present in very small grains, but those learning the art of panning are advised to begin with coarse material.



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Plate 55. Panning is useful in prospecting for and testing lodes as well as placers.

If the concentrate obtained by panning contains sulphide minerals, it should be roasted in the gold pan or other container for four or five hours over a hot fire. This is done to liberate particles of gold or other minerals that may be included in a sulphide mineral. The time of roasting may be reduced if the concentrate is first mixed thoroughly with an equal amount of potassium chlorate. After the chlorate has decomposed, the sample should remain on the fire for several minutes at red heat. The caked residue is then pulverized, screened, and panned.

The technique of panning is more fully explained in Chapter 16. Small pans are usually employed by lode prospectors, and some use a frying pan with the handle removed.

Any concentrate or tail obtained in the pan should be examined carefully with a hand-lens. If the prospector does not recognize the constituents, he may make tests, or send the concentrate to a laboratory for identification or analysis.

As panning is not infallible, if a large deposit is found it is desirable to have samples assayed, even if panning did not reveal the presence of valuable material.

USE OF AIR PHOTOGRAPHS

Although air photographs are not essential to conventional prospecting they have proved useful in several ways. One use is in the preliminary selection of a general area for prospecting, which has already been described. Further, they take the place of, or supplement, the topographical data on a map. In many areas it is possible to locate one's position exactly on a photo when that would be impossible with a map, by noting a particular small lake or island, group of trees, or other features.

Another way air photos are helpful is in planning the roving route or the systematic traverse to be taken for a few hours, a day, or a few days. The photos of many areas permit outcrops and larger rocky patches to be distinguished from overburden and vegetation, after a little experience and practice. This is commonly of great help but it is far from being infallible. Experience in the use of photos in connection with geological surveying has shown that although rock and overburden can be easily distinguished in this way in many areas, many other areas contain numerous outcrops covered by vegetation, including moss and lichen, or by a few inches of overburden. In the latter areas photos cannot be relied upon for eliminating places to be traversed on the ground. If forest fires have burned an area after photos were taken, the presence of outcrops bared by fire may not be suspected from a study of the photos.

In some areas the general trend of such geological features as bedding, contacts, faults, and dykes can be seen on air photos, either because of the shape and spacing of outcrops or because the features can be seen crossing patches of bare rock. These features collectively form what is sometimes called the *grain*. Knowledge of the general grain is often useful because it is usually better to plan a prospecting traverse to cross the grain rather than to travel parallel with it, in order to cross and investigate different conditions.

If rocks are well illustrated on an air photo a person having general experience in the geological interpretation of air photos can often form a fair idea of the actual kinds of rock and structures without visiting the area. After he has reached the area and studied some rock exposures to learn the actual natures of rocks and structures appearing on the photos, he can use this knowledge to help in interpreting other photos and in planning his prospecting. Photos commonly show geological details that could not be included in even the most detailed geological map, and they often show large-scale geological features that cannot be well interpreted from the ground. The recognition of rocks and structures on air photos is difficult to learn from written instruction. It should be learned from published illustrations, instruction in a course, or experience in the field. Some of the illustrations in this book are from air photos, many others are contained in other books, and the recently published Catalogue of Selected Air Photographs (Geological Survey of Canada Paper 68-21) contains many examples.

When a prospector reports to those who employ or finance him, or tries to interest a company in sending a representative to examine a discovery, it is almost essential that he be able to furnish a sketch. Nothing is more helpful in this connection than an air photograph on which significant items are marked, or a tracing on which roads, trails, main lakes and streams, main geological features, and positions of discoveries are copied from one or more photographs. The approximate scale and northing should always be indicated on such a tracing or photo.

Locations of spots visited, traverse lines, sample or specimen numbers, and notebook references can be marked on the surface of a photo or on a tracing. Another way is to punch a pin through the spot, circle the hole on the back of the photo, and write numbers or notes beside it.

PRELIMINARY INVESTIGATION OF A DISCOVERY

When an occurrence is found, a prospector is faced with the problem of how much time to spend exploring the showing before going on to look for other and perhaps better occurrences. The exploration and evaluation of mineral deposits are discussed in Chapter 14, more particularly in relation to the work that is done after a prospect of some merit has been found. The present section is confined to matters that come up in the course of prospecting rather than to those arising after it is decided to do considerable work on a discovery. Nevertheless, some of the later discussion regarding evaluation, sampling, and exploration applies also to the preliminary problems and will supplement the brief remarks made below.

Mineral occurrences are fairly common, but those that are large and rich enough to be mined are comparatively rare. There are no accurate statistics for this matter, but authorities generally agree that most mineral occurrences are too small to be classed even as prospects, and that fewer than one per cent of prospects become producing mines. Therefore, if a prospector is working in a region that is at all favourable he may encounter small occurrences fairly frequently. He should take time to investigate one of these only sufficiently to satisfy himself that it apparently does not lead to something larger. He cannot always be certain of this, but when in doubt it is probably best to note the location for possible future investigation and go on to look for a more promising showing. Some occurrences are sufficiently exposed to permit rapid estimation of their size and content. Others require removal of moss or shallow overburden. Some contain primary minerals that can be seen at the surface of the exposure or in pieces of rock chipped off with a hammer, and others are capped by gossans or other secondary minerals that should be picked or scraped in the hope of reaching primary minerals without too much loss of time. If the occurrence is obviously small, the prospector might decide not to take any samples or specimens, or he might take some and discard them later if he found something more promising.

The decision of whether to spend considerable time exposing an occurrence or prospecting in the immediate vicinity, or to proceed with general prospecting, is one for which there are no definite rules. There have been a few instances where seemingly insignificant occurrences were the only indications of important deposits masked by overburden or barren rock, but there have been many others where prospectors become unduly excited about the first occurrence they found. Much depends on experience and on the difficulties there would be to return another day. In general, it seems best to recommend a minimum of initial exposing and sampling, making careful note of the position and other particulars, and then continuing to look for other occurrences. After several days or weeks of prospecting, if several occurrences have been found, the most promising might be selected for closer attention, but if nothing else has been found, further attention could be given to the original one. Then, if it shows any likelihood of being large enough to be of interest, careful sampling and, if necessary, stripping or trenching would be done, as discussed in the first part of Chapter 14.

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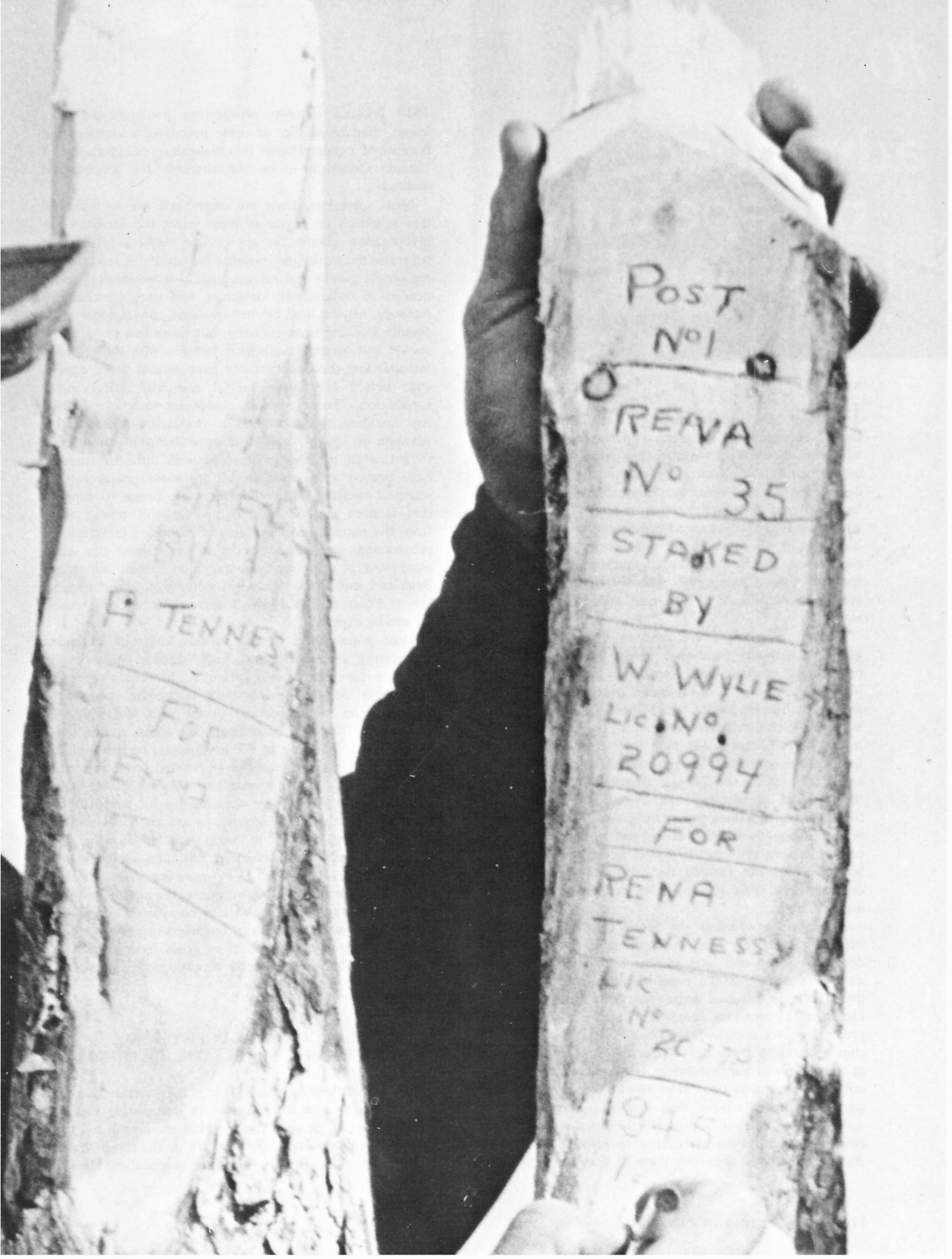
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10 advanced prospecting in general

In recent years prospecting in Canada has consisted largely of systematic programs undertaken by companies, with the aid of basic information published by government organizations. Such programs usually apply geophysical, geological, or geochemical approaches to searching for 'overburdened' or 'blind' deposits covered by overburden or rock (*see* Fig. 5). Advanced prospecting also includes the employment of conventional prospectors to work under supervision, the investigation of outcrops by scientists or specially trained prospectors who search for deposits that are especially difficult to recognize, and prospecting under water.

Various expressions are used to designate the entire group of activities mentioned above. The term 'scientific prospecting' has been used, but that is not fully distinctive because competent conventional prospecting has been fairly scientific for some time. 'Mineral exploration' is used but this expression is also commonly used to describe the testing of prospects rather than their discovery; also, this term can be confused with geographical exploration and is sometimes used to include conventional prospecting. 'Professional prospecting' can be considered to include full-time conventional prospecting. 'Indirect prospecting' is applied mainly to the discovery of buried deposits that cannot be seen and must be found by indirect approaches, but this does not include the advanced examination of outcrops. For these reasons 'advanced prospecting' seems most suitable.

Advanced prospecting was begun long ago when magnetic methods were used in Scandinavia to trace known deposits of iron and later to search for similar deposits, and when geologists first began to examine outcrops with the specific objective of finding workable mineral deposits. Geochemical methods were first applied early in the present century in Scandinavia and Russia, because of declining possibilities for the prospecting of outcrops. Except in connection with iron deposits, geophysical methods were not used in Canada until after World War I, and specific geological methods other than detailed geological studies and mapping did not begin until the intensive search for gold resulted from the increase in its price in 1934. Geochemical methods were not tried in Canada until about 1940 because outcrop prospecting predominated here longer than in smaller or more populated countries, and because of a general belief that the widespread glaciation of Canada caused it to be unfavourable for geochemical methods.

Most special methods are costly and are so technical that scientists or engineers must select the localities for investigation, choose the appropriate method, perform or supervise the work, and interpret the results. A few, including simple geophysical surveys such as those employing dip needles or radioactivity detectors, and some geochemical methods, can be used by well-qualified conventional prospectors working independently, but those less experienced should first become thoroughly familiar with the ordinary methods and should preferably have several years' experience before attempting special methods, unless under supervision. The only special equipment recommended for less qualified prospectors is a radioactivity detector if uranium is sought, and a mineral lamp if tungsten is sought; even the results obtained with these instruments have proved to be too difficult for some prospectors to interpret usefully. Many beginners are prone to suppose that modern methods and equipment will relieve them from the necessity of learning and practising conventional prospecting, and do not seem to understand that such equipment is only supplementary for certain objectives. Beginners may also be misled by well-meant advertisements for, or displays of, fairly small instruments or kits intended for use by experts.

Most practitioners of the various kinds of advanced prospecting are sincere and much reliable equipment is available for their use. Caution is, however, necessary concerning certain devices and techniques and some 'experts' who have appeared in the past and who will probably be followed occasionally by others of the same general kind. The lure of hidden mineral wealth and the uncertainties involved have long provided scope for tricksters and pitfalls for the credulous. In the Middle Ages, according to Agricola, men were hanged for purporting to be able to find mineral deposits by use of sticks such as are employed in attempts to locate water by 'dowsing'. Today there are still those who allege that they can find ore by such simple means, as well as by more mysterious devices, and even by 'mental' methods requiring no equipment. Disappointment and financial loss may be avoided by employing the services of scientists or engineers in good standing, or by buying only instruments of types recommended in standard textbooks or official reports, and by avoiding mysterious or secret devices.

GEOLOGICAL, GEOPHYSICAL, AND GEOCHEMICAL APPLICATIONS

The applications of these three sub-disciplines of earth science, which in some respects are not sharply distinct, are discussed in the next chapters, but are introduced here because matters related to them are discussed in the remainder of this chapter. All three applications had to

undergo periods of 'growing pains', reverses, and scepticism, but are now well established and recognized and of increasing importance. Greater attention is being applied to the further development of known applications and techniques as well as to discovering new ones, but still more emphasis will be needed in future as more obscure and lower grade deposits are sought. Geologists, geophysicists, and geochemists are co-operating and becoming more aware of one another's techniques and problems.

Geology is mentioned first because geological research and standard geological mapping are the principal bases for the initial selection of areas to be prospected. Specific geological approaches that may be included in a program include advanced interpretation of air photographs, more detailed geological studies or mapping to supplement available information, and the forming of theories (hypotheses) regarding the possible existence and location of individual mineral deposits. Geology is also discussed first because the results of geophysical and geochemical surveys must be interpreted geologically, and with reference to the geological environment concerned.

Geophysical methods are based on measurements of physical properties of rocks and minerals in the earth's crust. These methods are of two principal kinds, one dealing with phenomena that occur naturally and the other with effects of currents or rays imposed by geophysical equipment. Examples of the natural (passive) kind are measurements of magnetism, gravity, radioactivity, and alternating electric currents caused by a discharge of lightning or by sources in the ionosphere. Examples of the 'imposed' (self-powered) kind are seismic surveys in which reflections or refractions from deliberate explosions or hammer-blows are measured, and electrical methods in which currents are introduced into the ground and measured during and after they have passed through rocks or mineral deposits. Another example is fluorescence, caused by exposure to ultra-violet rays.

Regional geophysical surveys supplement geological mapping by providing data on the magnetic, gravity, seismic, electrical, and radioactive properties of rocks, thus aiding in the tracing of geological boundaries and structures beneath overburden. Surveys of radioactivity virtually measure the effects of only the surface of rock or overburden, but magnetic, gravity, seismic, and electrical methods can indicate conditions at depth and so provide data on deep-seated structural and lithological conditions. Regional magnetic, electrical and radiometric surveys are usually conducted from aircraft but seismic and gravity surveys are performed on the ground or from ships. Local surveys conducted to provide more detailed information for selected areas or to locate specific targets are made by the methods mentioned above when applicable, but largely by electrical methods, some of which can be performed either from the air or on the ground and others of which have been used only on the ground. A disadvantage of geophysical prospecting is that, although several methods help to indicate regions and areas for prospecting in depth, most of the methods now available for indicating specific targets do not penetrate as deeply as would be desirable. Unless used in drillholes, different electrical methods penetrate to maximum depths of about 500 to 1,000 feet, and there are reasons to hope that magnetotelluric methods capable of indicating good-conducting bodies in sizes representing a few million tons at depths of 2,000 feet may be developed. Magnetometers having high sensitivity can probably detect bodies of magnetite at greater depths.

The basis of geochemical prospecting is that many mineral deposits are surrounded or partly surrounded by minute quantities of some of the same elements that occur in a deposit. The techniques include systematic sampling surveys of rocks, soils, stream sediments, water, or vegetation, and the rapid analysis of very numerous samples to determine the contents of one or more metals. The results are plotted in various ways to permit consideration of contents above the normal 'background' amounts for the area concerned. Most geochemical techniques are applicable only as deep as the overburden in an area, or several feet into bedrock, or to the depth of circulating groundwater. Geochemical studies can, however, be applied more deeply to drill core or cuttings and to water in drillholes.

Sharp distinctions cannot always be drawn between geological, geophysical, and geochemical approaches, or between these and conventional prospecting. Nor is it always possible to distinguish between prospecting and testing. Although they are all branches or applications of earth science, it is desirable to distinguish them as completely and as objectively as possible for determining the effectiveness of prospecting methods, planning research and prospecting programs, planning and teaching courses, and titling articles, reports, and textbooks.

PROJECTS

Advanced prospecting projects carried out during the last decade or so ranged from fairly simple surveys involving one technique only, to very complex programs lasting several years, covering large areas, applying various techniques at different scales, and involving company, university, and government personnel. The latter participated in some experimental projects and in some projects in areas where it was desirable to obtain maximum information before construction of dams or smelters which would cause flooding or impede geochemical surveys by contamination from fumes.

Between the extremes mentioned above a fairly general procedure has been developed, which is modified to suit the area concerned, the metals or geological classes of deposits sought, the time and funds available, and the experience and preferences of the planners. Some planners tend to favour certain broad categories of methods and individual techniques, which to some extent come in and out of fashion. A program is usually commenced with office studies by senior company geological staff or a consultant, who review available reports, geological and aeromagnetic maps, and air photographs for a region or smaller area. A compilation of structural features and

lineaments made from air photographs by a firm is available for a fee. If suitably impressed by such preliminary reviews the planners select one or more areas to be investigated. If topographic maps are not adequate, or if useful geological data can be compiled, mosaics of air photos may be made or obtained. As considered necessary, the first field stage may consist of more detailed geological or geophysical mapping or air photography, or a reconnaissance geochemical survey, or combinations of any of these. 'Orientation' geophysical or geochemical surveys may be made over any known deposits in an area. If existing geological and aerogeophysical mapping does not have half-mile spacing of traverses, such surveys are commonly performed. Geological reconnaissance from aircraft, and the investigation of outcrops by conventional prospectors, may be part of the work at this stage.

The results of the first stage are studied in the field and at headquarters. If indications are favourable, localities are selected for 'follow-up' surveys that may be in the form of air or ground geophysical surveys, or ground geological or geochemical surveys. Use of two or more methods are commonly called 'integrated surveys' or 'combined programs'. Programs involving all approaches thought to be applicable are often called 'saturation prospecting' but no project is likely to exhaust all the possibilities that might be related to improvements in techniques, different interpretations, or changed demands for metals. By successive applications of different methods, at different scales, and after successive re-interpretations of results, anomalies are rejected or selected for tests. More than one geophysical or geochemical method is commonly required because some methods indicate anomalies resembling those of sulphide deposits, which in reality are caused by the presence of graphite or other minerals. Also, experience in many areas shows that most sulphide deposits consist of pyrite or pyrrhotite and are barren or virtually barren of desirable metals. Nevertheless, increasing numbers of valuable deposits are being found by these methods. Details of applications are too variable to be generalized further here. Additional information is available in many publications, some of which are listed below. Projects of these kinds require large expenditures, some extensive programs having cost several millions of dollars. Costs are not discussed further here because prices are changing and because lengthy generalizations of published information would be required. Further data on costs are provided by the paper by Morley (listed below), in volumes of "Canadian Mining Manual", in the statistical tables in volumes of "Canadian Minerals Yearbook", in the annual reports of some companies, and in articles on individual projects. Some of the information contained in such sources is difficult to generalize because some costs are quoted for entire regions or years rather than for individual discoveries, and because of different usages of the terms 'prospecting' and 'exploration.'

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DECISION MAKING

Although luck, hunches, intuition, and qualitative experience will undoubtedly continue to be factors in advanced prospecting, scientific approaches to decision making are being studied and applied more extensively because of greater emphasis on deposits that are hard to find and the availability of computers. These approaches are being applied to deciding the areas to be prospected, the spacings of lines and stations for traverses on land and in the air, the prospecting methods to be used, the selection of anomalies and occurrences to be tested or tested further, and the spacing of drillholes and sampling sites.

Theories for best results in searching, grouped as 'search theory', are based on research during World War II for locating military targets such as submarines. These theories have been developed as a type of operations research. Their more effective application to prospecting is considered to require better knowledge of initial probabilities and more adequate statistics on the abundance of ore deposits, the history of successes by various prospecting

methods, and the costs of prospecting, testing, and production.

Objective and reliable case histories are valuable guides in deciding techniques to be used and in evaluating and testing anomalies and mineral discoveries. In addition to the histories companies have retained for their own use, they have generously permitted publication of a considerable number of others. Publication of additional and more detailed histories as soon as possible after interests have been protected would undoubtedly assist future projects in general. Histories would be enhanced if they dealt with some failures as well as successes, if they indicated judgments as to which technique or techniques most influenced final decisions where more than one technique was applied, and if they were prepared in ways that permitted referencing or abstracting in mineral-deposits data banks.

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RECENT TRENDS IN SUCCESSFUL PROSPECTING

The best way of judging the effectiveness of prospecting methods is obviously to learn as well as possible the means of discovery of orebodies on which producing mines were based, and to generalize those data. The period 1945 to 1966 has been analyzed in this way by two studies in which discoveries were assigned to conventional, geological, geophysical, or geochemical methods or their combinations. Specific techniques within those four categories were not tabulated, but some details are available in published reports and articles.

A study published in the annual number of the *Northern Miner*, 1954, summarized the manner of discovery of "important" mines whose production was begun or resumed since the end of World War II. As this included mines being prepared for production it virtually covered the decade 1945–55. This study indicated that of 77 mines brought into production in 1946–55, 31 were old mines or partly proved prospects that had been re-activated, and 46 were new finds. Although some of the latter resulted from combinations of prospecting methods, an attempt to classify them according to manner of discovery indicated that 22 were found by conventional prospecting (including use of Geiger counters), 17 by drilling chiefly geological 'bets', and 7 by geophysical prospecting.

The writer analyzed the histories of mines whose production was begun or resumed in the decade 1956–66. A few mines whose plants were nearly completed were added, bringing the total to 175. Because many of the deposits had been found long ago and had become productive owing to changed conditions and so did not represent modern prospecting trends, a separate analysis was made of 55 of the 175 that were found after 1955. Where two or more methods were applicable to a discovery, the principal method was decided on if possible, and the other methods were considered to be supporting. Where information did not permit such a decision, all methods were classed as supports. Times from discovery to production averaged about 30 years for the entire group and 6½ years for the deposits found since 1945. Of that time, a year to 3 years was generally spent in mine preparation and plant construction after the orebody was proven. Additional data on recent trends of 20 unnamed prospects, some of which have since become mines, were studied. These results were tabulated and summarized by the writer in the *Canadian Mining Journal* (cited below). Corrections and supplementary data were invited and several were

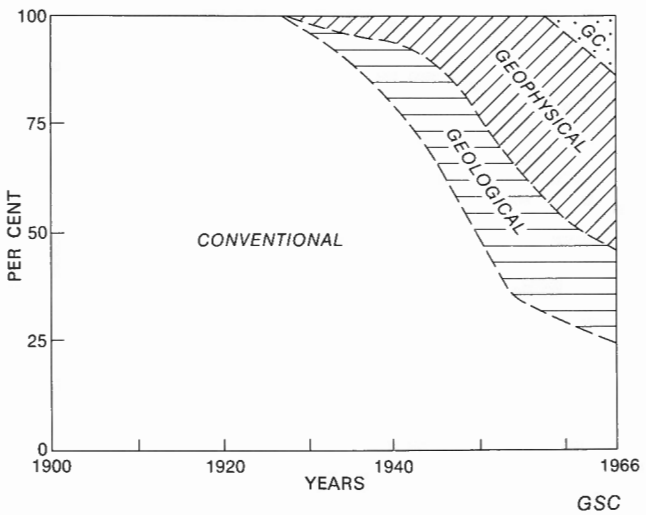

Figure 20. Approximate percentages of productive discoveries by the four main methods, 1900-1966. This gives a misleading idea of the amount of conventional prospecting in the earlier years unless it is realized that, regardless of the amount, the total for any year is 100 per cent.

received or published*, for which the writer is grateful. Most of the comments were for mines whose production was begun before or after the period reviewed, or those that cancelled out. Some changes in the totals were made possible, and the revised totals are tabulated in the following table. The trends are illustrated on Figure 20 which is considered to be reasonably accurate although the values for each year were not calculated exactly.

Methods of Discovery of Mines Whose Production Began 1956–66

	Conven.	Geochem.	Geol.	Geophys.	X[1]	XX[2]
All mines (178)						
A. Single or main method	92		50	25	6	5
Percentage	52		28	14	3	3
B. Supporting method[3]	5	10	14	4		
Mines found after 1945 (56)						
A. Single or main method	18		15	20	2	1
Percentage	32		27	35	4	2
B. Supporting method[3]	2	6	8	1		
Prospects (20)						
A. Single or main method	5	1	3	2	9	
B. Supporting method[3]	4	6	3	9		

[1] X, no main method indicated.
[2] XX, method unknown.
[3] The total numbers of 'supports' do not agree with the numbers of cases because no support was indicated for some discoveries, whereas more than one kind of support was indicated for others.

When cases for the period 1956–66 were being studied the writer also tabulated the mines according to their main metal or mineral and to the geological regions and structural provinces of the Canadian Shield in which they were found. Mines in Southern Province were included with those of Superior Province because the boundary had not then been defined fully. This and other adjustments have been attended to in the following table, which helps to illustrate recent trends in prospecting and mining and which could perhaps usefully be amplified by adding factors for geological features, size, or value, and used as a basis for estimating probabilities.

Main Product According to Geological Regions and Provinces

Region or Province	Au	Ag	Cu	Pb	Zn	Ni	U	Mo	Wo	Nb	Fe	Ind. Min.	Totals
Shield													
Superior	5	8	28	1	4	2		2			7		57
Churchill			7			5	7				5		24
Grenville							4				1		5
Slave	3												3
Bear			1				1						2
Southern			1			11	10						22
Cordilleran	4	3	11	2	1	1		4	1		8	1	36
Appalachian	1	1	9	3	1							1	16
Plains				1						1		11	13
Totals	13	12	57	7	6	19	22	6	1	1	21	13	178

* The method for the Vauze mine had been printed as geochemical although it had been counted as geological.

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UNDERWATER DEPOSITS

Near-shore deposits have been worked for many years in extensions of land-based mines or in shallow dredging operations. Canadian examples are the Wabana iron mine and coal mines at Sydney, which were extended far beneath the Atlantic, and the Eldorado mine at Great Bear Lake where veins found on the shore were mined partly beneath the lake. A large lake was drained to permit conventional mining of iron ore at Steep Rock. A shaft was sunk recently from a bulkhead in Lake Chibougamau to permit mining a copper–gold deposit found by geophysical prospecting. In several countries, including Canada, the possibilities of underwater prospecting and mining, as well as of extracting metals from ocean water, are receiving more attention. This interest results from awareness of the depletion of ore reserves, the successes of recent submarine oil and gas projects, increased concern for control of continental shelves, and improvements in several kinds of investigational equipment. Several types of deep-sea dredges, airlifts, and locks for 'in the rock' mining have been designed. Although it is considered that the capital costs of such equipment would be high, it may be used in the future if demands and prices for metals are favourable.

Underwater deposits in different parts of the world are of several types. Deposits under lakes include lodes similar to those found on land, detrital minerals in submerged parts of beaches, and unconsolidated sediments such as sand, bog-iron, and marl. 'In the rock' deposits beneath continental shelves include extensions of deposits found on land and similar separate deposits may be found. Detrital deposits near seacoasts result from wave erosion, deposition in deltas, and perhaps also from currents that destroyed Pleistocene deltas. Nodules of phosphorite are fairly abundant on continental shelves in some regions. Manganese nodules and 'pavements' containing smaller amounts of several other metals have been reported from several places away from continental shelves, and such nodules were dredged recently from the coast of British Columbia. Undersea flows of geothermal brines, analogous to the water of hotsprings on land, have been found and offer possibilities for extraction of certain elements. Sulphide deposits may have been formed beneath shelves or deeper parts of oceans by processes related to submarine lava flows.

In common with prospecting on land, searching for underwater deposits includes preliminary surveys to aid in selecting areas, followed by the seeking of specific deposits or anomalies, followed in turn by sampling and other tests. Many of Canada's shelf areas have been or are being covered by aeromagnetic surveys and by seismic surveys made from ships. Geological conditions have been extrapolated locally from observations of shores, reefs, and borings. More detailed geophysical studies have been made on frozen lakes, and geochemical studies have been made in some lakes. Geophysical surveys of lakes and seas have been conducted by instruments placed in small boats, or held or towed from them. Observations have been taken by means of underwater cameras, diving bells, submarines, and diving. In general, visibility is reported to be better at sea than in lakes, whose bottoms are commonly covered by a film of sediment. Samples have been obtained by dredging, by borings, by means of special drop-tubes, and by diving.

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DATA PROCESSING

Modern methods of processing data are increasing the efficiency of many methods of advanced prospecting and are making possible approaches that would otherwise have been impracticable. Applications of data processing will also probably be used increasingly in the accumulation, generalization, and evaluation of data on mineral discoveries. Data processing itself is not a new subject; the new features that have advanced the subject radically in recent years are related mainly to the growth of expert knowledge of electronic computers, their increasing availability, and improvements made possible by the use of transistors. Most Canadians are now acquainted with some kinds of data processing, such as are used for electricity bills, airline reservations, and election returns but the following brief outline may be a useful introduction to the discussion of some of the uses related to prospecting.

Modern methods of processing data are improvements of methods based on card-indexes, adding machines, and other devices that have been widely used for years. The handling of index cards was improved some time ago by punching holes at code-points on the cards, and sorting them by insertion of a hand-probe through appropriate holes. This facilitated the finding of a particular document. Mechanization of this system by 'feeling' punchings with rapidly moving keys or by blowing compressed air through the holes permitted rapid sorting of large numbers of cards. Systems of these kinds are still used in some accounting and statistical machines. Computing devices are as old as the abacus, the adding machine, and the slide rule. Adding machines operated by hand, and the later adding and calculating machines operated electrically, are examples of 'digital' devices using zero and the digits 1 to 9 in addition and subtraction, and also in multiplication or division by means of numerous additions or subtractions. A slide rule, in contrast, is based on logarithms, which are 'analogs' of numbers. In other words, the distances on a slide rule are logarithmic analogs of numbers which, when added or subtracted by moving the scales of the rule, permit multiplication or division.

Attempts to convert numbers into electronic signals and to add these by means of vacuum tubes began about 1930. Workable units were constructed some 15 years later but were not used extensively because of their large size, the frequency of tube failures, and the amount of heat generated by the tubes. The development of transistors has not lowered the cost of the equipment appreciably but has permitted compact, fairly trouble-free units that do not produce much heat. These 'computers', commonly called 'electronic brains', are electronic extensions of the human brain that permit at lightning-like speeds the 'reading and memorizing' of large quantities of data, and the transforming, compiling, adding, subtracting, or multiplying of them as required. Complicated mathematical formulae can be handled by making such computations. Various systems are used for either digital or analog computers. In most systems the 'input' consists of punched cards, punched paper tape, or a variety of forms on which codes are marked with a pencil. The data are then transferred to magnetic tape and stored until wanted. The 'output' is usually in the form of numbers printed on continuous paper forms. Such numbers may be the calculation required or they may be references to a desired file, book, etc. An

advantage of modern computers is their ability to print tables and plot graphs and certain maps speedily and accurately. As with any popular new development there is a danger of expecting the impossible and of misuse. The model or other subject to be treated must be conceived and 'programmed' adequately and the data must be coded accurately.

Data processing serves prospecting, geology, geophysics, and geochemistry in two main ways. It provides more efficient and comprehensive storage and cataloguing of the results of field and laboratory investigations and other studies; and increases the speed of mathematical calculations. Use of electronic computers not only facilitates more efficient calculations but also permits mathematical applications that were not used formerly because of the time and expense required. 'Models' for alternative choices or plans or approaches to a problem can be 'programmed' for a computer, and the most desirable result can be decided after the data have been processed. This is the essence of what is called 'operational research'.

In a broad sense files of data include publications, unpublished documents and drawings, card-catalogues and reels of magnetic tape. Automated files of largely numerical and alphabetical data are also called 'data-banks'. Such files are divided broadly into 'archival' files that are kept for reference by the public, and 'project' files that are usually confidential. Project files may comprise data being used while a project is under way and which is to result in publication, or may comprise data kept confidential after a project is completed. The use of computers for archival files of data such as mineral identifications and chemical analyses permits storage and retrieval of useful information which has now reached proportions too great for publication and too difficult to retrieve even if published.

The term 'model' is used frequently in connection with data processing and quantitative approaches to problems. In this sense a model is an object or formula for organizing or 'structuring' a study or theory. Models are classed as scale, mathematical, and conceptual. Examples of scale models are actual models of topographic relief, mine working, and crystals made to scale. In a sense, scale drawings used in solving problems in structural geology are scale models. A mathematical model is an expression containing variables, constants, or parameters (i.e., constants or variables distinguishing specific cases). A conceptual model is a mental image of a natural phenomenon, expressed diagrammatically, qualitatively, or quantitatively. An example is the use of multiple working hypotheses in a geological study and the selection of one hypothesis or conceptual model as being most satisfactory. Mathematical models are subdivided as deterministic, statistical, and stochastic process models. Deterministic models are solved without experiments or observations in the field, but their validity may be tested by experiment. Krumbein cites as an example the use of a formula to determine the velocity of settling of a particle of certain size in a liquid having a particular viscosity. Statistical models deal with variables, constants, and parameters, together with one or more random factors. Models of this kind are used in analyzing geochemical and geophysical data, including such considerations as standard deviation and skewing. Another example is in the mathematical treatment of samples taken from a mineral deposit at random intervals. A stochastic process model is a kind of statistical model that provides for a specific random sampling process. An example is the mathematical treatment of a sampling project in which random selections are made according to specific rules.

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11

geology in advanced prospecting

THE ROLES OF GEOLOGISTS

Geology is applied in various ways to many phases of the mining industry. Most fundamental is standard geological mapping and basic research on geological problems. Most such research projects have a bearing on prospecting or mining. At the other extreme is the assistance of geologists in the operation and evaluation of mines, which began in Canada about 40 years ago. The first geologists employed by companies had to undergo a period of acceptance, but sound use of geology has become a vital part of mining. Large operating companies have at least one geologist, and most companies also obtain the services of consultants.

Between these extremes is a wide range of geological activities more specifically within the scope of this chapter and the later one on the evaluation and testing of prospects. These activities include the selection of areas and methods for advanced prospecting programs and, if required, the carrying out of additional geological mapping or field or laboratory studies on one or more particular geological problems related to a program. Also included is the application of geological reasoning and hypotheses to the possible location of individual deposits, the interpretation of geophysical and geochemical anomalies, the appraisal of mineral discoveries and the geological guidance of their testing, and the compilation of data on the geology of known deposits.

The methods used in geology are largely qualitative but are becoming more quantitative. Geologists have to try to develop inferences and inductions from scanty data as a large proportion of the bedrock surface is obscured by overburden and because of the limited opportunities for observing beneath the surface, or they have to try to infer deductively and then seek proof or disproof. Much use is made of multiple working hypotheses, either consciously or unconsciously, from which the most plausible explanation is selected.

If an area for prospecting is chosen because it includes known prospects or mines, or because of expected improvements in transportation, or for some other non-geological reason, the next step is to learn as much as possible about the geology of the area from publications and records, and then from field observations if work is to be continued. Other areas are selected on the basis of known or speculative geological favourability. As this is largely a matter of individual experience and judgment few details have been published on the subject. These phases of the industry are highly competitive so any favourite methods of selection and 'geological prospecting' possessed by companies and consultants are likely to be cherished.

In an unpublished account of a discussion panel D. R. Derry's comments on the selection of areas on the basis of general lithological, structural, or metallogenic similarity with areas having a good record are as follows:

> Having made the first general selections . . . . . the next stage of screening is by the application of what may be called 'limiting factors', the chief of which are:
>
> (a) Accessibility—either in respect to the prospecting itself or, more commonly, from the fact that transportation facilities for the economic utilization of any deposit found may not be available within the near future.
>
> (b) The amount of open ground or at least ground on which options are likely to be available on reasonable terms. This, of course, is the factor that rules out many of the more obvious areas that might be selected on the basis of previous history of discoveries.
>
> (c) The extent of previous coverage by similar methods or equipment to those proposed for use in the program. This limiting factor is often difficult to assess partly because the extent of prospecting or geophysical surveys by other organizations cannot always be determined, but still more because of uncertainty about the efficiency of the equipment or methods that might have been used.
>
> Accordingly, after the first general selection of a number of areas has been made, or should I say juggled, the limiting factors, such as remoteness versus previous attention, are weighed in order to arrive at a final selection.
>
> Such a standardized and routine method probably gives as good a statistical chance as any other and it would, in all probability, miss some important, unusual deposits, as has happened from time to time in the past. Thus unconventional or poorly planned approaches may be successful in spite of the even longer odds.

Geological inferences for the selection of specific sites for geophysical or geochemical work, or for direct trenching, drilling, or careful examination of outcrops, are largely inductive and based on the obtaining and compilation of detailed observations of the surroundings. Less use has been made of deductive speculations, probably because they have been regarded as 'arm-chair' geology and are costly to prove or disprove, and also because geologists have been needed in other capacities. Increasing demands for suitable prospecting areas and specific drilling sites may result in more opportunities being given to geologists with a flair for conjecture and a reputation for common sense, and more funds being spent on testing their inferences.

The interpretation of anomalies and mineral discoveries is usually the responsibility of geologists. It requires experience and imagination, as well as sound basic training in geology, and is a subject on which little specific advice has been published. As mentioned earlier, the writer considers that the release of detailed case histories on the manner of discovery of important deposits, including the ways in which indications were interpreted and screened, would greatly benefit geologists in future. This should also help to narrow the ratios between anomalies and mineral occur-

rences, on the one hand, and productive deposits on the other. The ratio of occurrences to productive deposits is estimated to be at least 1,000 to 1, to say nothing of anomalies for which no ore-mineral could be found. Furthermore, the account of an extensive program in the Canadian Shield states that only 1 per cent of occurrences of pyrite or pyrrhotite contained even a little metal other than iron. It seems most desirable, therefore, to apply additional research, compilations, and data processing to attempts to improve interpretation and screening.

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TOPICAL NOTES

Geological applications to prospecting are based on a number of sub-disciplines most of which are inter-related but can be discussed as separate topics. The following are brief notes on some of the principal topics, and selections from the extensive literature on them.

Origins and Ages of Deposits

The origin and time of formation of known deposits is obviously of great importance in selecting areas and specific localities in which to seek more or less similar deposits. For many deposits the origin and age are obscure because of conflicting evidence and lack of knowledge of conditions at the depths at which mineralization took place long ago. The annual reports of the Mineral Deposits Sub-committee of the National Advisory Committee on Research in the Geological Sciences review the research being done on these problems in Canada, including a comprehensive study of the Coronation deposit involving many approaches and sub-projects. Repetition of these reviews here would occupy too much space. Recent reviews have stressed the need for studies of the entire environment of deposits, including their geochemistry, host rocks, and relations to geosynclines, as well as physical-chemical, structural, and mineralogical studies.

Research on isotopic ages of minerals from deposits and their host rocks is proceeding but seems to offer more problems than the isotopic dating of orogenies. Studies of stable isotopes show promise of clarifying the mode of origin of certain deposits.

Many genetic problems are world-wide in scope, causing some members of the sub-committee to stress the desirability of noting projects in other countries, avoiding duplication, and stressing research on types of deposits that are exemplified particularly well in Canada or that contain metals in short supply in North America.

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Lithology and Stratigraphy

The significance of plutonic, volcanic, and sedimentary rocks as sources or hosts for mineral deposits has been discussed in connection with the genesis of deposits. The types (lithology), stratigraphic positions, and ages of such rocks are significant factors in selecting areas and methods for advanced prospecting. Many of these factors cannot be separated from the relations between structures and stratigraphy mentioned below, but the following factors are at least partly applicable to the present topic: porosity, permeability, susceptibility to fracturing and shearing, chemical composition with respect to the precipitation of metals from fluids, restriction of circulation fluids by relatively impervious rocks, and the different types (facies) of rocks developed in various kinds of geosynclinal, platform, shelf, cover, and metamorphic environments.

Relationships between specific metals or kinds of deposits and kinds of host rocks permit a few broad generalizations such as the common associations of gold and base metal deposits with belts of ancient Precambrian volcanic and sedimentary rocks, the associations of molybdenum, tin, tungsten, and uranium with granitic rocks, the association of other uranium deposits with conglomerates, the association of certain kinds of lead–zinc deposits with limestone and other carbonate rocks, the occurrence of native silver in

or near diabase, and the relationships of many deposits to volcanic rocks, including rhyolite tuffs. On the whole, however, lithological considerations are more local than these statements might suggest, and generally require interpretation for individual districts.

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Tectonics and Structures

Relationships between regional tectonic and local structural features and certain types of mineral deposits have been recognized for a long time. Much has been published on the subject and additional information is being added as the relationships and their applications become better understood. Tectonic features of regions and areas may influence the selection of areas for advanced prospecting, and local structural features and structural anomalies may indicate specific sites for prospecting and help in the evaluation and testing of anomalies and mineral discoveries.

An indication of the amount and kind of information available on the subjects is obtainable from the symposium volumes on tectonics listed in Chapter 5 and those on structural geology of Canadian ore deposits cited at the end of this section. When the first structural symposium was being planned to mark the fiftieth anniversary of the founding of the Canadian Institute of Mining and Metallurgy, a volume on the geology of Canadian deposits, including their genesis and other topics as well as structural aspects, was considered. It was soon found, however, that this would require more than one volume and that there was no likelihood of obtaining suitable papers on the more controversial subjects, such as genesis, in time for the occasion. The committee in charge therefore limited the symposium to regional, areal, and mine structures, for which much unpublished data, largely empirical, could be obtained. It was available because operating companies had been employing geologists long enough for them to become familiar with the structural features of mines and districts, and because the period was one in which many geologists considered that structures offered considerable guidance to prospecting and testing while more fundamental explanations for the origin of deposits was, in many cases, lacking. The first volume was followed by a supplementary one. More recently, volumes on the tectonics of the Canadian Shield, Appalachian Region, and Western Cordillera have included papers on their related mineral deposits. Symposia have also appeared on the relations of strata-bound deposits to stratigraphy, thus helping to synthesize the whole subject of Canadian deposits.

As examples of the broad, tectonic aspects of the subject, mention may be made of the current emphasis on the Western Cordillera, the belts along the Superior–Churchill boundary in Manitoba and farther east in Ungava and Labrador, and the Abitibi belt in Superior Province. Among other features, attention is being given to the relations between deposits and unconformities along these belts and elsewhere. Interest in unconformities is based partly on the possibility of tracing the source of detrital minerals in conglomerates and other sedimentary rocks overlying unconformities, or in the upper parts of the ancient surfaces (regoliths) beneath unconformities.

Examples of successful local applications of structural and stratigraphic geology include the discoveries of the Con-Rycon gold ores and the Pine Point lead–zinc ores in Northwest Territories. After a large gold-bearing shear zone was developed at the Giant mine a detailed study was undertaken by Consolidated Mining and Smelting Company with the hope of discovering the continuation of the zone on the opposite side of a large fault; by matching several displaced dykes the structure was interpreted, and diamond drilling based on this resulted in discovery of orebodies along what became known as the Campbell shear zone. Although interest in the Pine Point area stems from an occurrence that Indians showed to prospectors in 1897–98, the actual orebodies were found through patient geological studies begun because prominent faults in Precambrian rocks miles to the east strike toward the area, and because aeromagnetic maps indicated the probable continuation of the faults in the basement rocks beneath Paleozoic cover. Because the ore is in a reef in Paleozoic dolomite, a possible explanation of the relationship of the faults to the ore is that ancient fault-scarps may have provided platforms suitable for the growth of reefs.

The Vauze copper deposit near Noranda was discovered by drilling based on an interesting application of structural and stratigraphic data. Several orebodies in the area were observed to be situated near intersections of two series of lineaments visible on air photographs. Drilling was done near another of these intersections, where the rocks at the surface were stratigraphically higher than the favourable horizon.

The discovery and testing of uranium deposits in the Beaverlodge area provide other examples of structural

applications. The diary of one of a pair of experienced prospectors employed on an elaborate program states that they found radioactivity associated with what they were the first to recognize as a large fault. They tested this systematically with a Geiger counter and in conventional ways, and so discovered the first signs of the Ace deposit. After hundreds of additional occurrences of pitchblende had been found in Beaverlodge area and had been subjected to preliminary testing, the consulting geologist recommended thorough drilling of the Ace showings because the fault-zone was more favourable theoretically than the setting of other showings. This resulted in establishment of the first uranium mine in Canada after the opening of the one at Great Bear Lake. Further studies at the Ace and other deposits in the area showed that many of them are associated with zones of intense crushing (mylonitization) and that many rake southwestward. These and other structural generalizations influenced further prospecting and testing by drilling.

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Mineral and Metallogenic Provinces and Maps

A tendency for particular metals and types of deposits to be confined to, or most abundant in, certain regions or belts was observed long ago. About the end of the last century the name *metallogenic* (or analogous names) was applied to such 'provinces' or belts. Interest in the subject largely subsided until after World War II, although in Canada, at least, 'mineral maps' showing the locations of mines and selected prospects were issued. These usually embraced the whole country, or political provinces. Some were printed on simplified geological maps and others on topographic bases corresponding to those of geological maps, so the two could be compared.

The need for additional supplies of minerals has stimulated interest in metallogenic provinces and maps. Maps have been issued or are being prepared in many countries, and an international committee is compiling from these a map of the world. Many geologists have commented that maps of these kinds, and research on such provinces and belts, are useful, but differences of opinion exist regarding the nature and nomenclature of the provinces and the maps illustrating them. The entire subject appears to be in a healthy state of development. For this reason some authorities are reluctant to use the term 'metallogenic' for provinces or maps until the differences between metallogenic and geochemical provinces are designated, and are using 'mineral province' and 'mineral-deposits map' tentatively. Further refinement of Canadian metallogenic and geochemical provinces and maps to illustrate them should result in much better understanding of the mineral potential of various areas.

Metallogenic and mineral-deposits maps published recently in Canada are of two general kinds. One shows past and present mines on a simplified geological base, symbols of different shapes and sizes representing past and present productive deposits and their sizes. Examples are the Metallogenic Map of Manitoba (No. 66–2) and the Mineral Deposits Map of Canada (1252A). The other kind shows the pattern of distribution of all known mineral occurrences, and some also include known sampling results above an arbitrary quantity. Examples of these are maps by the Geological Survey of Canada dealing with iron, uranium, lithium, tin, beryllium, and molybdenum, as well as experimental composite maps compiled from these and several unpublished maps (*see* Paper 60-33).

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Advanced Mineralogy

Mineralogical studies are vitally related to many of the topics mentioned here, particularly genesis, alteration, fluorescence, zoning, and the interpretation and evaluation of discoveries. One role of mineralogy in genetic studies of primary deposits is to provide accurate identifications, information, and reliable samples — commonly for minerals occurring in extremely small particles and total quantities — for isotopic age determinations and studies of stable isotopes. Detailed mineralogical studies are sometimes required to show whether or not a deposit is of replacement origin, or to show the presence, degree, and nature of supergene mineralization. Paragenetic studies show the relative times when particular minerals in a deposit were formed, and help to explain the changing character of the mineralizing process. They may also indicate possible changes in a deposit with depth, and possible horizontal zoning within a deposit or in a mining camp. Some early reports are considered to have contained unduly lengthy descriptions of paragenesis, but it obviously has a useful place in genetic studies. Detailed mineralogical investigations are also part of studies on the metamorphism and re-mobilization of ores. The synthesis of minerals in a laboratory helps to elucidate the conditions under which natural deposits were formed.

In the interpretation of prospecting discoveries special mineralogical studies may be undertaken to try to settle obscure cases of suspected supergene origin, and other genetic questions. The ease or difficulty of treating ores is also an important consideration, which may be affected by the identification and composition of minerals, by grain-sizes, or by the way in which grains of one mineral species are enclosed in grains of another.

For some advanced mineralogical studies field geologists collect specimens for laboratory investigation by mineralogists. Other instances require both field and laboratory work by mineralogists. Laboratory investigations are now aided by greatly improved techniques and equipment for preparing polished sections of mineral aggregates, for microscopic study and photography, for separating minute grains of specific minerals, for X-ray identifications of minerals, and for analysis of minerals. The latter includes use of electron probes that indicate the composition of a grain while it is being viewed microscopically.

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Fluorescence

Fluorescence was mentioned briefly in connection with conventional prospecting, especially in regard to tungsten. Fluorescence has additional uses in mineralogy and possibly in certain advanced prospecting. Strictly speaking, it is a geophysical phenomenon but is so closely related to mineralogy that it warrants discussion here.

Fluorescence is a 'glow' caused by the excitation of the atoms of certain minerals under the influence of ultraviolet rays, that is, rays whose wave lengths are shorter than those of ordinary light. Improvements have been made in recent years in portable lamps that produce ultraviolet rays with a minimum of ordinary rays that lessen the effect, and which are lighter and more compact than earlier types such as shown on Plate 56. A more modern one is shown on Plate 61. Some lamps are designed to produce rays of both long and short wave lengths. One should never look directly into the beam from an ultraviolet lamp, or remove the filter without looking away or turning the lamp off, as the rays can damage the eyes.

Unfortunately, some specimens of a mineral may fluoresce visibly whereas others may not, and a single specimen may show different fluorescent colours, probably because of the presence of impurities. Therefore the listing or illustration of the colours is of limited help in quick identification of minerals. The main practical uses of fluorescence are in providing a simple and reliable means of distinguishing between those that fluoresce visibly and those that do not, and in making tests for fluorescence on 'beads' produced by blowpiping, but the fluorescent colours of the mineral itself may help in identification when other methods are not available.

Fluorescence is probably most useful in helping to detect scheelite, the principal ore of tungsten, and to evaluate scheelite deposits and sort scheelite ores. Scheelite resembles other minerals that do not fluoresce, and therefore a fluorescent lamp is helpful in looking for it. This may be done at night, or under a cloth hood or canvas sheet in daytime, or at any time of day in underground mine workings. Scheelite (and its molybdian variety formerly



R. E. Folinsbee 90863

Plate 56. Estimating the scheelite content of large lumps from a deposit by using an ultraviolet lamp under a tarpaulin. Note rock trench (partly filled with rain-water) excavated to expose deposit.

called 'powellite') is virtually the only ore mineral of tungsten that fluoresces. A great shortage of tungsten existed early in World War II, but the situation was eased by the recovery of scheelite from a large Canadian gold mine; this mine was found to contain much more scheelite than was formerly supposed, when a geologist examined the underground workings with an ultraviolet lamp. Another geologist devised a method of estimating the percentage of tungsten present in scheelite deposits by measuring the fluorescent patches and comparing them with the total sampling area.

Fluorescence has also been valuable in detecting certain other minerals, such as secondary uranium minerals, but a radioactivity detector is usually better for uranium prospecting under Canadian conditions.

Fluorescence has been used in geological studies not directly related to prospecting, whereby certain granitic and gneissic rocks have been differentiated from others on the basis of the presence or absence of fluorescent zircon.

The following is a list of some of the more common minerals that fluoresce, with notes on their behaviour. New information is being discovered from time to time, so the notes should not be considered as complete or final. Extensive tables are included in the book by S. Gleason, listed below, from which some of the following data were obtained.

Apatite does not usually fluoresce but specimens from some localities do.

Barite generally shows yellowish to white fluorescence, rarely blue.

Brucite commonly fluoresces with white to bluish or greenish white.

Beryl is not usually fluorescent but some specimens exhibit weak yellow or pale green fluorescence.

Calcite is often fluorescent, the range of colours being great, partly due to weathering.

Celestite occasionally shows white and greenish white fluorescence.

Cinnabar is not fluorescent but the presence of mercury can be detected by using a quartz ultraviolet light and a special screen. When a specimen containing cinnabar is heated in a flame, black shadows appear on the screen. Care must be taken to avoid breathing the poisonous fumes.

Feldspars may exhibit cream or bluish white fluorescence.

Fluorite was the first mineral studied in connection with fluorescence. It generally displays yellowish white or blue fluorescent colours, sometimes green, yellowish green, white, or cream. Most of the colours are more vivid under 'long' rays.

Gypsum is generally non-fluorescent but pale cream to yellow fluorescence occurs occasionally.

Scheelite generally shows vivid blue fluorescence when pure, and yellow when impure; therefore material that shows blue fluorescence is likely to be more valuable than that showing yellow.

Spodumene occasionally shows orange, yellow, or cream fluorescence particularly after about 10 minutes of exposure to the lamp. When melted by blowpiping it fluoresces blue.

Uranium minerals. Many secondary uranium minerals, such as autunite and uranophane, show yellowish green fluorescence. Gummite, a variable mixture, commonly exhibits violet fluorescence.

Zircon. Some specimens show bright orange fluorescence, which might assist in detecting the mineral and estimating its quantity in rocks and placer concentrates.

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Wall-rock Alteration

Many epigenetic deposits are surrounded by zones of altered rocks caused by fluids associated with those that formed the deposits themselves. The zones are called *haloes* or *aureoles*, and are three-dimensional. They are generally wider, sometimes much wider, than the deposits and thus may be valuable clues for those who can recognize and interpret them, although many alteration haloes are not accompanied by significant deposits. Several types of alteration, such as silicification, chloritization, alteration to clay minerals, skarns, pyritization, and the hematitic alteration that accompanies most pitchblende deposits, can be determined with the unaided eye by persons familiar with them. This is particularly true in the fresh exposures of diamond-drill cores and underground workings, where alteration has sometimes been a valuable guide in testing deposits or searching for additional ore at operating mines by indicating that additional searching should be done nearby. Strongly contrasting alteration such as that sometimes accompanying pitchblende can, however, be a clue in early prospecting. Some other kinds of alteration can be detected only by microscopic or analytical studies, and the weakest and most remote are equivalent to the dispersion haloes useful in geochemical prospecting. Further research by combined field and laboratory investigations is desirable to provide more complete data on the relationships of alteration to different kinds, sizes, and grades of deposits and different kinds of host rocks. The improved and more numerous aids now available, such as data processing, spectroscopy, mineral identification, fluorescence, and differential thermal analysis may facilitate studies of these kinds. Inclusion of critical data on the usefulness of alteration would be a helpful addition to case histories.

Cryoluminescence and thermoluminescence may be applicable to some detailed alteration studies. These phenomena are related to certain minerals that do not normally fluoresce under ultraviolet light but which do so at sub-zero and elevated temperatures. Luminescent haloes of both kinds around sulphide replacement deposits are reported by McDougall.

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Photogeology

General matters concerning the use and availability of air photos and enlargements and mosaics made from them were covered in Chapters 8, 9, and 10. Besides use of such aids in connection with the selection of areas for advanced prospecting they may, if terranes, scales, and other factors are suitable, assist greatly in any additional geological mapping or studies done, in the prospecting of outcrops, in selecting specific geologically favourable sites, and in interpreting geophysical or geochemical anomalies. If adequate topographic maps are not available, photos can be used as bases for plotting and unadjusted tracings can be made from them, or photos or mosaics can be adjusted for distortion by such instruments as an orthophotoscope. If a suitable base map is available, geological or other data can be transferred to the map by eye, by proportional dividers, by sketchmaster, or by other means.

As is to be expected in a large and diversified country, the usefulness of air photographs ranges from conditions where rock exposures are excellent to conditions where few or no outcrops can be seen although they are present and are obscured by vegetation. In places where exposures are good it is seldom possible to be certain of rock types or structures from inspection of photos only, but if a good geological map is available for comparison, fairly reliable estimates may be made before entering the field. Experience on the ground commonly permits reliable extrapolations of the extensions of rocks, contacts, and other structures. In some areas where exposures are scarce or must be searched for on the ground, extrapolations can be attempted in places where the grain of bedrock appears to be traceable in shallow overburden or by selective vegetation. Photos commonly show useful features for prospecting in glacial drift, and geomorphological studies in connection with prospecting for placers may be aided by photos.

A catalogue of air photos selected as being illustrative of many geological conditions in Canada, prepared recently by Bostock (1968), indicates photos that would probably assist students or company geologists unfamiliar with conditions in certain areas.

If available photos are unsatisfactory because of scales, shadows, or for other reasons, additional ones may be obtained by contract. In this connection it is interesting to note that an article on photo uses in Siberia states that small-scale photos did not provide adequate information and that very detailed ones failed to reveal the features sought, but that an intermediate scale of 1 to 15,000 was useful. It appears, therefore, that comprehensive projects in Canada might benefit from experimental photography at different scales.

A method called 'stereogrammetry' has been applied to structural mapping in the Rocky Mountains by Haman and Ozsezginer. The strike and dip of linear and planar elements visible on air photographs were analyzed by stereographic projection.

A special type of printing of air photographs called log E is now available for photographs obtained from the National Air Photographic Library. These bring out details that are lost in parts of some ordinary contact prints owing to over-exposure. Log E prints cost twice as much as ordinary contact prints, but an order for photos on any given flight line can be filled partly by conventional contact

prints and partly by log E prints for places where the extra cost is warranted.

Improved types of colour film seem likely to make the use of colour air photographs more widespread, although more costly. In most parts of Canada the rocks are not sufficiently well exposed to make direct use of rock colours particularly useful, but in suitable places gossans and other coloured features might be detected. Other uses may arise as certain types of vegetation tend to grow over certain kinds of soils or rocks, and these vegetation colours might be well suited to colour photography. Experimental studies of colour of water caused by algae related to some geological features have been carried out. An advantage of colour photographs is that they enlarge well.

Experiments are being made with infrared scanning in an attempt to learn whether temperature changes in rocks can be detected significantly, and with respect to detecting fluorescence properties of rocks and mineral deposits by low-altitude air reconnaissance at twilight, using special sensors.

Experiments have also been carried out with respect to the use of radar because it can penetrate vegetation and may be able to record metallic content of surface material. Possible geological applications of high altitude photography from aircraft and satellites are being studied. None of these experimental aspects of photogeology and related subjects appears to be sufficiently advanced to warrant departure from conventional black and white photography in most instances, at present, but developments are being watched with interest.

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Industrial Minerals and Rocks

As described in Chapter 4, the geology of industrial deposits has both similarities and differences compared to metalliferous deposits. Geologists familiar with or specializing in certain kinds of industrial deposits are needed for the following reasons. Many consolidated non-metalliferous deposits require special knowledge of the minerals and geological characteristics of their specific type. The bulkiness and relatively low unit costs of structural materials dictate that deposits of suitable specifications be utilized as close as possible to centres of population or industry. Guillet states that specialists are required to prospect for such deposits, to carry out resource surveys for municipality, township, or other governments, to advise in community planning, and to be familiar with deposits of potential value in anticipation of industrial needs. He believes that such specialists should have special training in Pleistocene and Paleozoic geology, in economic geology and mineral economics, in the dressing and beneficiating of the material concerned, and in geography, transportation, industrialization, and political science.

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Advanced Examination of Outcrops

Considerable scope exists for careful scrutiny of outcrops by geologists or conventional prospectors supervised by geologists. Many outcrops have not been prospected exhaustively, especially for low-grade deposits and deposits containing valuable minerals of rather nondescript appearance. In some regions, particularly in parts of the Canadian Shield, outcrops that have never been seen by conventional prospectors or geologists can doubtless be found by intensive traversing or by stripping 'carpets' of moss and other vegetation. Semi-skilled crews could be used for finding, stripping, and indicating outcrops, and experienced prospectors, some of whom cannot be surpassed for 'having a nose for minerals' and knowing how to go about the preliminary tracing and exposing of showings, could be briefed on particular objectives and used for examining the outcrops.

Tracing Float in Glacial Drift

The simpler principles of following float to its source by direct observation or panning have been discussed in connection with conventional prospecting. More refined methods for tracing float dispersed in glacial drift, commonly as much as a few miles from the source, have been used extensively and successfully in Scandinavian countries and are of growing importance in Canada, where conditions are comparable. Most of these methods are used by a geologist skilled in glacial geology, or a team including at least one such person, and a good deal of equipment may be necessary. Some of the methods could be used by advanced

prospectors lacking formal training, if they studied the subject. Tracing float in these ways may lead directly to an outcropping deposit, but more frequently it would be expected to indicate only a general area in which further geological, geophysical, or geochemical work might be successful in guiding diamond drilling.

The manner in which vast glaciers and sheets of ice accumulated, advanced, and melted away over most parts of Canada during the Pleistocene Period is outlined in Chapter 2. In many areas this process was repeated one or more times during Pleistocene time. Fragments of rock of various sizes, including occasional pieces of float from mineral deposits, were frozen into those glaciers and ice sheets, carried forward with the advancing ice, and finally deposited in moraines and other forms of drift when the ice melted. Most of the stones and boulders in glacial drift are of fairly local origin, and this is particularly true of many ore minerals, which are too soft or soluble to withstand travelling great distances. In Canada, float containing ore minerals, found within or near the boundaries of the Canadian Shield or other geological provinces favourable for the occurrence of mineral deposits, may repay attempts at tracing, particularly if the float is fairly abundant. On the other hand it would probably be difficult or impossible to trace boulders of Precambrian rock containing ore minerals found on the Plains far from the Canadian Shield. 'Stone counts' of the kinds of rocks and minerals found within sample areas of drift may indicate whether it is feasible to try to trace float containing a particular mineral or favourable rock.

The chances of tracing float to its origin are probably best in the higher parts of the Cordilleran region, where most glaciers moved down valleys. Some float may have been transported beyond its source valley by ice that overrode the valleys, but this is probably not so in most cases. In most other parts of Canada the movement of ice was less restricted and the tracing of float may be more difficult, particularly as it may have been moved in one direction by one stage of glaciation and in a different direction by a later stage.

Float may be widely scattered and offers little chance of being traced. It may be strung out in a fairly straight line to form a 'train' that can be traced back to the vicinity of its approximate source. These have generally been called 'boulder trains' but Dreimanis advocates the name *indicator trains* because they may contain pebbles rather than boulders, or minute fragments detectable only by chemical or other tests. Float is also found in glacial fans that may be traced to their approximate places of origin by plotting occurrences or sampling results on a map and drawing through the outermost points lines that should intersect near the apex of a fan. Lee has studied glacial fans near gold mines at Kirkland Lake, Ontario (1963), obtaining positive results on basal till southeast of known orebodies, and negative results in areas of no known or suspected deposits. He concluded that the method was fairly easy where float was transported only once, but difficult or impossible where float was re-transported and re-deposited. He is developing a system called 'glaciofocus' for the sampling and tracing of minerals in esker gravels or basal till. This method is expected to be useful, in suitable areas, for direct prospecting and for helping to evaluate geophysical, geochemical, and geological anomalies.

Post-glacial deltas, which do not appear to have been studied or tested systematically, might repay further study.

Evidence regarding the direction of ice movement, and other features, can be obtained for some areas from published maps, and, for Canada as a whole, from the Glacial Map of Canada and the Glacial Map of North America. Evidence may also be obtained by observing in the field such phenomena as striations, flutings, drumlins, and other streamlined topographical features. Striations are scratches on outcrops caused by small sharp rock fragments frozen in the ice; flutings are larger parallel troughs gouged in the surface of outcrops; and drumlins are oval-shaped hills of glacial drift that are oriented in the direction of ice movement and that may be observed on air photographs. Striations, flutings, and drumlins usually indicate only one of two possible directions of ice movement and it would be difficult for prospectors who are not well versed in the subject to determine which of the two it actually was. In most instances they would have to test both directions or obtain information from a published map. Those who make a special study can obtain evidence from such phenomena as stoss-and-lee, crag-and-tail, nail-head striations, friction cracks or crescentic gouges, end moraines, washboard moraines, and till-fabric analysis. Descriptions of these features are found in some of the publications listed below and in other works on glacial geology.

Studies of eskers and of drift-covered valleys made recently by Lee offer hope that these features may be useful in specialized prospecting. Eskers are common in Canada, and in many places contain the only readily available rock and mineral fragments from the bedrock. The distance of transport is believed to be fairly short because esker-depositing streams are thought to have been of limited duration and overloaded with sediment. Buried valleys are of potential interest both as indications of bedrock conditions and as possible sites of placers. The existence of valleys may be controlled by the relative hardness of rocks, by geological structures, or by the presence of metalliferous minerals that weather more rapidly than the surrounding rocks. Preliminary studies were made by use of high-level air photographs, interpretation of the bedrock surface beneath overburden, and seismic geophysical surveys.

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Processing Geological Data

General matters concerning data processing and the National System for Storage and Retrieval of Geological Data in Canada were mentioned in the last chapter. This system includes standardization of such features as coding of geological names and terms, referencing and geographic co-ordinates, and files on mineral deposits. These features are already facilitating the cataloguing and referencing of libraries, file data, minerals, fossils, and other geological data. Advantages include more ready exchange of fundamental data, consistency in recording, selective retrieval and comparison of data, easier searches of literature and other files, and storage of information supplementary to publications.

Besides the storage and retrieval functions of data processing, the use of computers permits more applications of mathematics to geological problems. Mathematical studies were made in the past mainly on mineralogical and petrographical data and in connection with geophysical and geochemical anomalies. Most geological work was qualitative rather than quantitative because of the limitations of handling large amounts of statistical data and because of the time and special training required for complex calculations of models. There are few, if any, aspects of geology that cannot be better understood and applied after more quantitative and mathematical studies. Geological approaches to advanced prospecting include the selection of areas for prospecting, the formulation and theoretical testing of geological hypotheses or concepts for the existence of mineral deposits, and the geological side of the appraisal of anomalies and deposits. Research on metallogenic provinces and the preparation of metallogenic maps will doubtless be improved and speeded by more mathematical treatment of data. Consideration is being given to the likelihood that comprehensive data for factors of the environment and methods of discovery of a particular known ore deposit, together with coded data for information contained on geological or metallogenic maps, could be processed by a computer either directly or after treatment with statistical or conceptual models.

Techniques of operational research were applied by Allais (1957) to the potential distribution of mineral deposits beneath the desert of Algeria, based on statistics of known deposits. He concluded that the statistical distribution obeyed the following laws: lognormal law for values, Poisson's law for probabilities, and normal law for parameters smaller than map-types. This approach was applied by Graham (1964) to an area of two square miles in Slocan district, British Columbia. The area was virtually unprospected because of overburden, and the study was based on counts of deposits known in adjacent areas. The probabilities of discovering mines, important prospects, prospects and showings (mineral occurrences), and the costs of discovery were analyzed. He concluded that the method provided a realistic and useful appraisal.

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12

geophysical prospecting

Geophysics, a branch of experimental physics dealing with the earth, is a long established science that has contributed greatly to the understanding of geological phenomena. The application of geophysics to searching for mineral deposits was begun long ago, but the development of modern geophysical prospecting was not begun until after World War II.

Geophysics is considered to date from about 1600 when Sir William Gilbert discovered that the earth itself is a huge magnet that controls the direction of a compass needle. This prepared the way for other investigations related to magnetism. Observations on earthquakes also contributed to the beginnings of geophysics. Crude Oriental instruments for measuring the direction and intensity of earthquakes were used 20 centuries ago, and the use of accurately measured arrival times of shocks at different stations to determine the location of an earthquake was suggested by John Mitchell in 1761. Nearly a century later Robert Mallet theorized that different geological formations might alter the speed of travel of earthquake waves through them. Measurement of variations in the force of gravity, caused by differences in the composition and position of different components of the earth's crust, form another main branch of geophysics. The law of gravity was deduced by Newton in 1687 and the first measurement of gravitational force was made by Cavendish a century later. Measurement of the force at different localities was made possible by the invention of a field instrument, called a torsion balance, by von Eotvos in 1880. The discovery of radioactivity in 1896 and the establishment of its principles by Rutherford a few years later led to another main branch of geophysics. The Geiger tube, invented at that time, made possible the development of field instruments for measuring variations in radioactivity caused by different rocks and mineral deposits, which began in 1932.

Soon after publication of Gilbert's theory magnetized bars were used in Sweden to prospect for deposits of magnetic iron. Better instruments such as dip needles, were used to trace known iron deposits and search for additional ones, and led to development of the various magnetometers used today. By 1917 the torsion balance was used to search for salt deposits, and a few years later its use in outlining structures that might contain petroleum was begun. The use of vibration detectors during World War I was quickly followed by application of seismic methods for aiding in the study of structures in known or potential oil fields. Use of the electrical properties of rocks and mineral deposits as a possible means of detection was begun in 1930, when it was discovered that most sulphide deposits generate a natural electric field. Studies of electrical effects caused by introducing electrical currents into the ground from artificial sources soon followed, but the main developments in electrical methods did not begin until the present century. Geophysical techniques for prospecting for mineral deposits by surveys made on the surface and in mines were improved and used increasingly during the period between the two world wars. The general development of aviation during the second war and the invention of a magnetic method of detecting submarines from aircraft caused the great developments and widespread uses of airborne geophysical surveys that have characterized the post-war years. Experiments are being carried out at present on methods involving infrared photography and other methods of sensing and measuring such phenomena as heat emitted from various locations on the earth's surface.

Applied geophysics has become a large, complex, and quickly changing branch of earth science. It has been largely responsible for discovery of many of the orebodies found in Canada in recent years, as explained in more detail in Chapter 10, and it has also been helpful in appraising some deposits and in aiding the search for extensions of known orebodies. The subject is treated in several textbooks and more recent developments and applications are described in numerous articles, a few of which are listed at the end of this and later sections. The remainder of this chapter is a fairly up-to-date summary of the principal methods and is intended to provide introductory information for students and non-specialists and to include adequate information on the simpler magnetic and radioactivity methods used by conventional prospectors and geologists. P.J. Hood and G.D. Hobson of the Exploration Geophysics Division of the Geological Survey of Canada wrote the magnetic methods section and seismic and gravity methods sections, respectively; L.S. Collett of the same division wrote the introduction to the section on electrical methods. The remainder of that section is similar to one supplied by Canadian Exploration Geophysicists for the previous edition of this book, except that a section on induced polarization methods has been added by the writer, who also prepared the section on radioactivity methods.

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MAGNETIC METHODS

by P. J. Hood

The Compass and Magnet

A magnet may be described as a piece of material, commonly iron or iron alloy, capable of attracting pieces of the same material. This phenomenon is called magnetism and is the physical property involved in geophysical prospecting instruments such as the compass, dip needle, and magnetometer. Even the magnet itself is a useful aid in identifying some minerals.

If a needle is drawn repeatedly in the same direction across one pole of a magnet, the needle itself becomes a magnet. If this needle is suspended from its centre by a fine thread it will set itself in a north-south direction and dip downward. Regardless of how the needle is moved it will always return to the same position, thus showing that a directional force is acting upon it. The end pointing towards the north is referred to as the north pole, and that pointing to the south, the south pole. The earth itself acts as a huge magnet, and the magnetized needle aligns itself in the direction of the earth's magnetic field. This field may be considered as having two components of force, one horizontal, the other vertical.

The needle will not point directly towards the geographic or true north because the earth's north magnetic pole is at present on Bathurst Island, District of Franklin, Northwest Territories. In recent years it has been moving northward at about 5 nautical miles per year.

The horizontal angle between true north and a suspended magnetized needle that points to the magnetic north is called the declination, (navigators call it 'variation'). The vertical angle between a suspended needle and the horizontal is called the angle of dip or the inclination. A compass indicates the direction of the horizontal component; a dip circle measures the inclination of the earth's field from the horizontal; and a magnetometer measures the magnitude of the earth's field, or the vertical or horizontal components of the field.

Magnetic Properties of Rocks

The magnetic properties of common rocks may generally be ascribed to the presence of magnetite (oxide of iron); other magnetic minerals make minor contributions, if any. The individual grains of magnetite in the rock possess two kinds of magnetism. The first kind is the magnetism induced in the magnetite grains by the earth's magnetic field; such magnetism would disappear if the earth's field were removed. The magnetism induced in a particular rock is proportional to a physical property called its magnetic susceptibility. The other kind of magnetism is the remanent (permanent) magnetism of the magnetite in the rocks. Rocks may acquire remanent magnetism in a variety of ways, some producing a 'hard' and others a 'soft' component of magnetism. The hard components correspond to the remanent magnetism of a permanent magnet, and the soft components correspond to the magnetism that can be acquired by a piece of soft iron. Igneous rocks acquire permanent magnetism after they have cooled below a critical temperature (580°C for magnetite). The direction of remanent magnetism has been shown to be accurately aligned in the direction of the earth's field at the time the rock cooled. Thus the total magnetism of a rock is the sum of its induced and remanent magnetism. Surprisingly, the earth's field has reversed itself a number of times throughout geological time. Thus where a rock cooled in a reversed field, the remanent magnetism will also be reversed in direction. If the remanent magnetism is greater than the induced magnetism of the rock, the associated magnetic anomaly is also in the opposite sense to the earth's magnetic field, i.e., it causes a negative anomaly. Several examples of this phenomenon have been found in the Canadian Shield; for instance, diabase dykes in the Fort Hope area of northwestern Ontario show negative anomalies. This effect is, however, much more common in younger basic rocks such as those that occur at the margins of the continent. Lightning can also produce a small negative anomaly, 20 feet or so in diameter, in a rock outcrop. Negative anomalies are also associated with rocks containing ilmenite and hematite, the effect being due to spontaneous reversal caused by a special magnetic property of these minerals. For example, the ilmenite–hematite orebodies at Allard Lake in southwestern Quebec produce distinctive negative magnetic anomalies.

Identifying Magnetic Minerals

All prospectors should be equipped with a compass, the simplest of all geophysical instruments. Apart from its

customary uses, certain minerals can be identified by means of a compass, and certain types of rocks and buried geological contacts can be located.

Magnetite and pyrrhotite are the most magnetic minerals; when placed near a compass they will readily attract the needle. Franklinite, jacobsite, chromite, and ilmenite attract a compass needle less strongly. When testing the magnetic attraction of a mineral, it is best to set the compass on a level place and bring the specimen up to the needle several times each time oriented in a different position.

A compass may be made more sensitive to the magnetic effects of rock specimens by also using a fairly long bar magnet to counteract most of the horizontal component of the earth's magnetic field near the compass. The compass should preferably have a fairly short needle and should be placed on a flat non-magnetic surface, such as a wooden chair, and rotated until the needle points north. On a line at right angles to the compass needle, i.e., east or west, the bar magnet is centrally placed with its north pole pointing north. If the magnet is not labelled the polarities may be determined by using the compass, because like poles repel. Move the bar magnet along the east-west line keeping it parallel with the north-south direction until the compass needle swings slowly and comes to rest in an east-west direction. This is, of course, the position where the horizontal component has been effectively cancelled, and where a very slight rotation of the magnet will cause the compass needle to rotate through 180 degrees. The increased sensitivity of the system can be demonstrated by using a Canadian nickel coin. If it is held centrally above the compass with one face parallel with the glass and rotated with the fingers, the compass needle will also rotate following the direction of permanent magnetization across the coin.

The common magnet (either horseshoe or bar type) can also be used by the prospector to great advantage. A bar or horseshoe magnet may be used to identify magnetic minerals in one of the following three ways: one is to balance the magnet delicately and to bring the sample up to it; a second is to suspend the magnet on a string and move it up to the sample; a third method is to powder the sample and test the powder with the magnet. A surprisingly small amount of magnetic material can be detected in the latter manner. To determine roughly the amount of magnetic material present in a sample, first crush a sample, make a thorough separation by pulling the magnet through the crushed material several times, cleaning the magnet after each pass, and when no additional material is picked up, compare the magnetic concentrate with the remainder.

Magnetic Surveying with a Compass

To trace buried rocks with a compass there must be a large relative difference in the magnetic attraction of the rock being traced and its surrounding rocks. This can be tested by bringing specimens of both the type of rock sought and the surrounding rock up to the compass and noting the deflection of the needle as previously described. If one type moves the needle a great deal and the other does not, a magnetic difference exists and it should therefore be possible to trace the formation magnetically. However, even though a hand specimen may not be magnetic enough to move the compass, the whole mass of a given rock unit may contain sufficient magnetic material to do so.

To map formations and contacts with a compass, the following field procedure is recommended: cut a picket line across the contact or rock trend, making sure that the line is long enough to extend well beyond the contact or well within or beyond the rocks to be mapped. Beginning at one end of the line, accurately take the compass bearing of the line every 100 or 200 feet and record the readings. Small changes of 5 to 10 degrees in the bearing of the line (i.e. deflection from normal) will indicate a change in the magnetic character of the underlying rock and very possibly a change in rock type.

The deflection of the needle may be great, as shown on Figure 21. In this instance the bearing of north-south picket lines was taken at intervals of 100 and 200 feet across 'iron-formation'. The direction taken by the compass needle is shown by small arrows. Diabase dykes, gabbros, syenites, granites, slates, and volcanic rocks, as well as iron-formations, have been mapped in this manner. If very strong magnetic deflections are observed over a small area, the chances of a local concentration of magnetite are great, but whether it is of ore grade can be determined only by sampling.

The Dip Needle

Although the compass may be used for locating contacts between bands of rock of widely different magnetic characteristics, it becomes less useful as the magnetic characteristics of the rock types become more alike. A more sensitive instrument is then required to differentiate between the two magnetic zones; for this purpose, the dip needle is more useful.

The dip needle was developed from the dip circle, which consists essentially of a delicately balanced magnetic needle pivoted on a horizontal axis. If the dip circle is held so the needle is free to swing in the vertical plane of the magnetic meridian (the direction of the earth's magnetic field at a given point), the needle comes to rest pointing in the direction of the total magnetic field, and thus provides a measure of the angle of dip of that field. The dip needle now used for prospecting is a variation of the dip circle, in that the needle is provided with a movable counter-weight attached to one end. In the northern hemisphere, the weight is placed on the arm that has south-seeking polarity (*see* Pl. 57). The counter-weight balances the needle at an arbitrary angle to the inclination (dip) of the earth's magnetic field when the dip needle is oriented in the plane of the field. The use of the counter-weight introduces a gravitational force that acts on the needle against the magnetic force. The gravitational force is relatively constant from one area to another, whereas the magnetic force varies in direction and intensity from one observation point to another, thus varying the position of rest of the needle. By moving the weight it is possible to

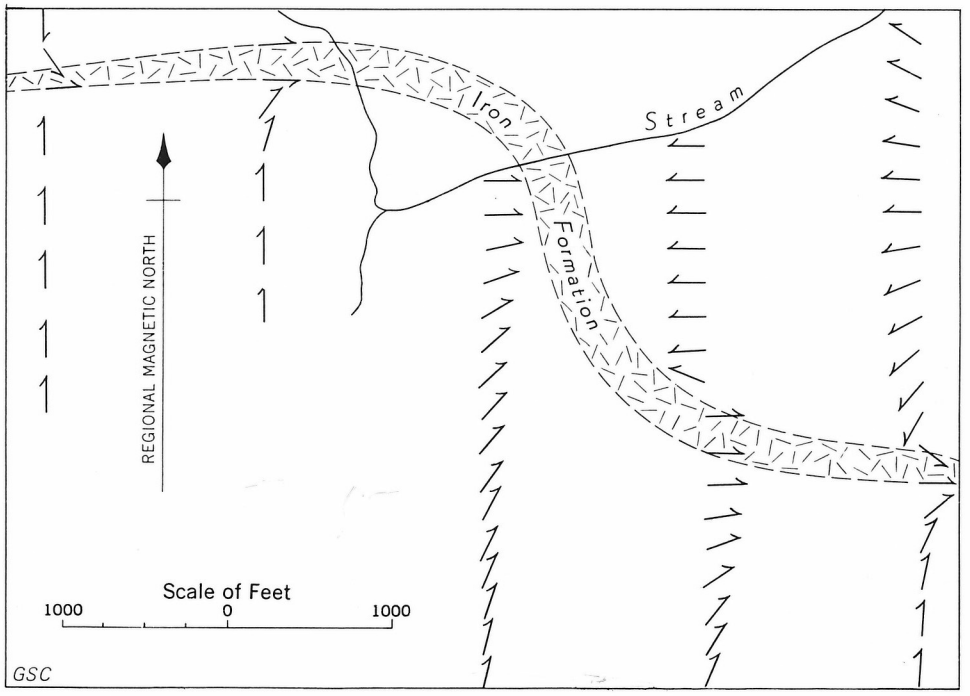

Figure 21
Diagram illustrating how a band of iron-formation may be detected by a compass survey.

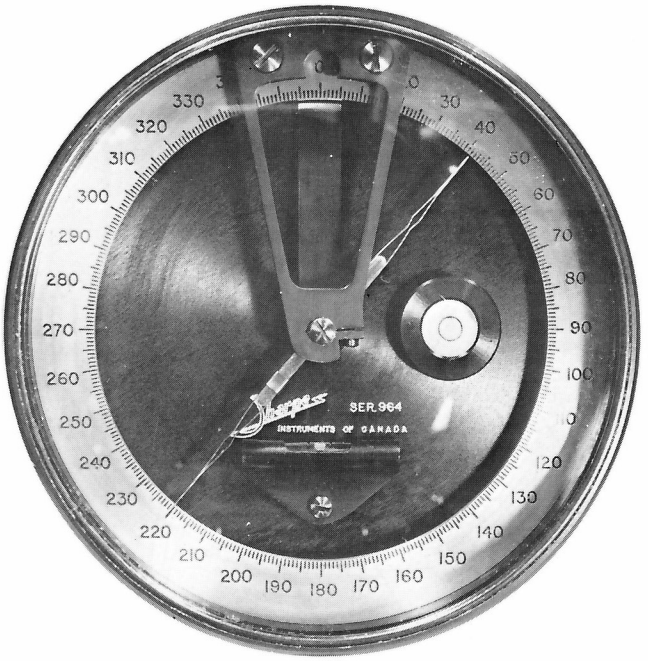

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Plate 57. A dip needle.

rebalance the needle to a nearly horizontal position for the area being surveyed, thereby increasing the sensitivity of the instrument. However for greatest sensitivity the needle should be at right angles to the dip of the earth's magnetic field.

In using all forms of magnetic instruments the operator must exercise extreme care not to have any pieces of iron on his clothing or body, or otherwise close to the instrument, as these will cause compasses, dip needles, and magnetometers to give false readings. A key chain, pocket knife, belt buckle, geological pick, even zippers on clothing are possible sources of error in magnetic readings.

Dip-needle readings will show the relative changes in the intensity or dip of the earth's magnetic field. Therefore, it is important that an operator establish a routine procedure in making observations, so that the only relative changes the dip needle indicates are the changes in the magnetic field, and not changes in the manner of operation. For this reason, readings are taken with the instrument oriented so that the needle is swinging in the plane of the earth's magnetic field. This orientation and the reading may be obtained by the following procedure:

(1) Hold the instrument flat so the needle is in a horizontal plane and release the needle. A levelling bubble is often provided to ensure that the dip needle is horizontal for this 'azimuth' (horizontal direction) reading.
(2) Observe the direction of magnetic north.
(3) Get a firm footing facing magnetic west.
(4) Raise the instrument to a position directly in front of the face so that the needle will swing in a vertical plane, thus making sure the vertical plane of the instrument is aligned with the plane of the earth's magnetic field. To carry out this movement, many geophysicists cup the instrument with both hands, and, keeping the upper parts of their arms in front of and close to their bodies, the dip needle is swung upwards from the horizontal to the vertical position in a single, uncomplicated movement.
(5) Read the position of the north end of the needle with the second levelling bubble horizontal.

Many sources of error in the use of the dip needle can be minimized by testing before making a survey and by care in operating. Some of the sources of error are in the actual manipulation of the instrument, and some are caused by mechanical defects within the instrument. A beginner might well practise by making a survey over a known magnetic body.

Generally the dip needle is held in the operator's hands and its orientation and level are only approximate. Ideally, the instrument should be level, vertical, and exactly in the plane of the earth's magnetic field. Some dip needles are not provided with a level, but are intended for near-level operation obtained by hanging the instrument from a single point so that gravity can act as a means of levelling. Experience has shown that the position of the needle may vary as much as 5 degrees from vertical and as much as 5 degrees from being parallel with the earth's magnetic field before the readings of the dip angle are affected by even 1 degree. With a careful operating procedure, it is possible to place the instrument within 5 degrees of being parallel with the earth's field and within 2 degrees of vertical, and thus sufficiently eliminate the effects of these errors.

Some of the mechanical factors that may introduce errors in the operation of a dip needle are:

(1) Defective bearings, such as pitted jewels or accumulation of dirt in the bearings.
(2) Defects in the pivot points such as pits, irregularities, and blunted ends.
(3) Gradual demagnetization of the needle.

The results of these defects can be observed in the performance of the instrument. Failure of the dip needle to repeat its readings at any given location, irregularities of the swing of the needle as it comes to rest, and any jerkiness in the behaviour of the needle, are symptoms of faulty operation. When such symptoms are noticed they should be taken into consideration in future use of the instrument, until such time as it can be repaired by a qualified repairman. The needle movement should always be locked when the instrument is being transported to prevent damage to the suspension.

Mapping the Results

If extreme care is exercised in taking readings with the dip needle, the data observed can be plotted on a map, and contoured in a way comparable to the contouring of elevations on a topographic map. Let us assume that dip needle readings are observed at 200-foot intervals along picket lines spaced 400 feet apart and that the points of observa-

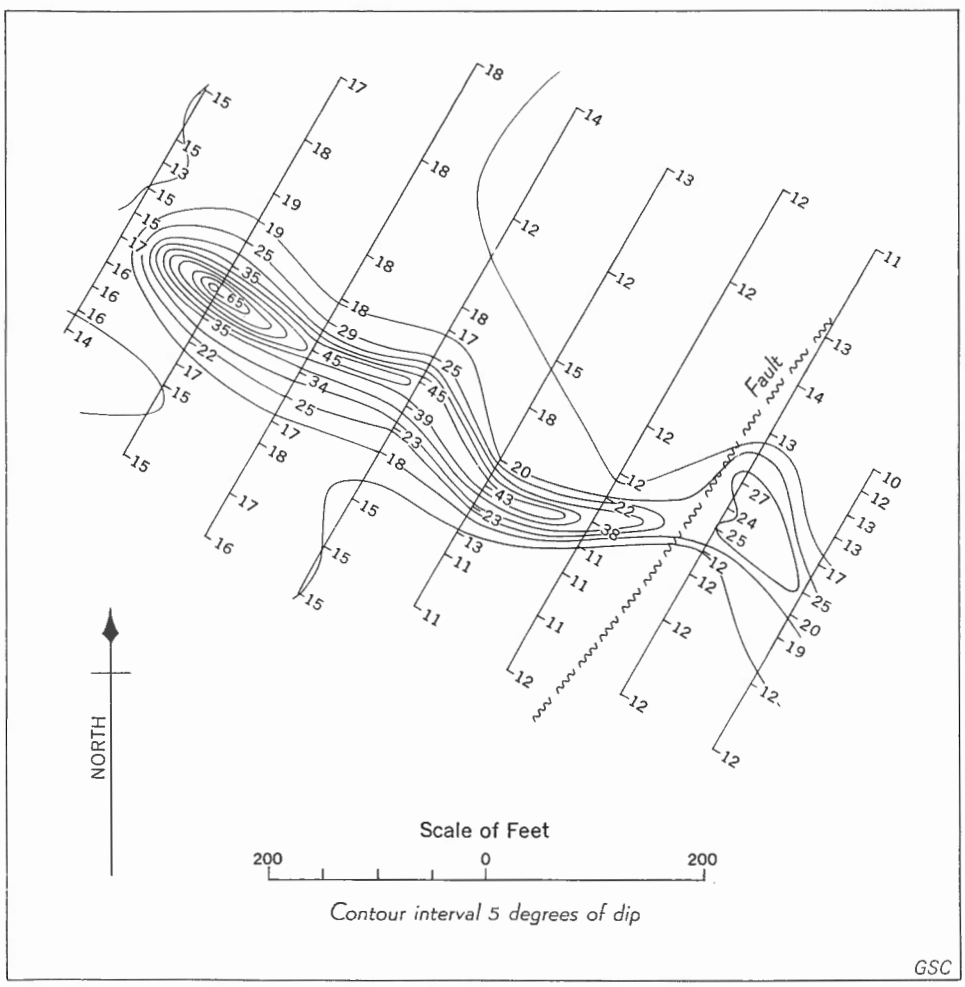

Figure 22
An example of a dip-needle survey.

tion are surveyed. These points can then be plotted to scale on a plan and the actual dip-needle readings can be marked at the respective locations. Contour lines may be drawn to join readings of equal value and thus make the observations easier to interpret, as shown in the accompanying figure. One must, of course, use judgment in estimating the position of magnetic values for the desired contour at places between the points where readings were taken.

A feature on a magnetic map produced by readings either above or below the normal background value for the area is called an anomaly. Thus the most easily recognizable anomaly will be one produced by closed magnetic contours. Whether or not an anomaly has significance depends on the nature of the problem or the rocks being investigated. For example, bands of magnetite would cause strong anomalies, whereas diabase dykes containing only a little magnetite would cause a difference of only a few degrees as compared to readings over ordinary rocks cut by the dykes.

The dip needle is most readily applicable to rapid reconnaissance for magnetic anomalies that are associated with, or indicative of, geological structures, rock types, or mineral distribution. It is particularly applicable for locating iron-formations; tracing faults in highly magnetic material; tracing dykes and igneous contacts; and, if the rocks are suitable, for helping to map the boundaries between geological formations more accurately than can be done from scattered outcrops.

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Ground Magnetometers

The compass and dip needle have been used in the search for iron ore for at least three centuries. These devices are quite satisfactory for this purpose if a deposit is strongly magnetic, but a more sensitive instrument is required to detect less magnetic bodies. The higher sensitivity of the magnetometer makes it useful not only in the search for magnetic iron ore but also in the location of weakly magnetic rocks and ores.

The vertical-force magnetometer measures the variation of the vertical component or downward pull of the earth's magnetic field. Horizontal-force magnetometers, measuring the horizontal component or northward pull, are employed when working in equatorial regions where the vertical component is very small. The earth's magnetic field is measured in units to which the name 'gamma' has been given by exploration geophysicists: this 'gamma' should not be confused with the gamma rays referred to on radioactivity measurements. The total intensity of the earth's field in Canada is about 60,000 gammas.

Magnetometers designed for scientific observatories appeared about 100 years ago, but it was only in 1915 that the German, Adolf Schmidt, designed the first field instrument, which he called a magnetic balance because it measures or 'weighs' the intensity of the magnetic field instead of merely showing the angles of declination or inclination. The Schmidt magnetometer consists essentially of a pair of magnets mounted on a suspension similar to that used in precision chemical balances, namely a quartz 'knife edge' resting on quartz supports. The magnets are properly counterbalanced to remain in a horizontal position when the magnetic field is normal. The influence of the horizontal component of the earth's field is cancelled if one orients the instrument so that the rotation axis of the magnet system is aligned in the magnetic east-west direction. An attached eyepiece is used to magnify the deflections of the moving system. The deflections are proportional to the variations of the vertical component of the magnetic field. Ground magnetometers of the Schmidt type are the kind described in most textbooks on geophysical prospecting now available.

The advent of transistors has made possible the manufacture of light-weight portable electronic magnetometers for use in ground magnetic surveys. There are two main types, the fluxgate and the proton precession magnetometers. These electronic magnetometers have to a large extent replaced the magnetic-balance type; they are more versatile, easier to use, and survey reading can be obtained in a much shorter time. Ground fluxgate magnetometers now available commercially are all hand-held, suspended on a strap around the operator's neck. The instrument is levelled by using a circular bubble mounted on the instrument, and the vertical field is read directly from a meter. Proton precession magnetometers have a separate measuring element that is not sensitive to orientation; a measurement of the total field is obtained by pressing a button and waiting a second or so for the reading to appear as a number on a special electronic 'readout' device or, sometimes, on meters. Of all the types it is the simplest to use. The fluxgate instrument does, however, have a much greater range, and is the instrument for use over strongly magnetized iron-formation.

Ground magnetometers are delicate instruments that require servicing by specialized technicians. They go out of order fairly often, and this may remain undetected by the field operator. Magnetometers used by persons unfamiliar with their construction and theory of operation should be given periodic check-ups and calibrations.

Another difficulty in making magnetic measurements with sensitive instruments arises because the earth's magnetic field is not constant, but is subject to fairly regular daily variations of moderate to small size (usually between 25 and 100 gammas) as well as to intensive disturbances known as magnetic storms. It should be pointed out here that magnetic storms have nothing to do with the weather, but are related to solar disturbances that also cause bad radio reception. They can be detected only by magnetic instruments. Geophysicists meet these difficulties by not using ground magnetometers during magnetic



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Plate 58. Reading a fluxgate magnetometer at a survey station.

storms and by making corrections for the smaller daily variations by check measurements at base stations. However, in making magnetometer maps for mining purposes it is usually sufficient to plot and contour the uncorrected magnetometer readings. Corrections for daily and temperature variations may be made as outlined in standard geophysical texts, if a more accurate map is required.

Interpretation of Ground Magnetometer Readings

Magnetometers are useful as direct prospecting instruments in the search for magnetic orebodies such as magnetic iron ore or complex sulphide deposits containing pyrrhotite. Numerous orebodies have been found in this way. Unfortunately, few magnetic anomalies are caused by mineral deposits but, in an area such as Sudbury or Noranda where magnetic ore is known to occur, most magnetic anomalies displaying certain characteristics are worth drilling. Careful mathematical analysis of magnetic anomalies, when done by competent geophysicists, will usually yield information as to the depth and width of the body causing the anomaly, and the intensity of its magnetization. Such an analysis may serve to differentiate between mineral deposits and igneous rocks. Generally speaking, the depths at which a magnetic body — whether it be magnetic ore or a rock that is more magnetic than its surroundings — can be detected increase with the size of deposit. Therefore, small deep-seated magnetite deposits commonly are not recorded by magnetometers.

Valuable non-magnetic minerals may be discovered by means of a magnetometer if they are associated with magnetic minerals or rocks containing them. Typical examples are asbestos-bearing bodies of serpentine and quartz–diorite dykes containing gold-bearing veins.

A magnetometer can be used to locate ore-bearing structures concealed by overburden, when it is known that they lie at a predetermined distance from a belt of magnetic rocks having no economic value. The most celebrated case of the use of the magnetometer in such an indirect way was the discovery of the western extension, beyond a major fault, of the famous Witwatersrand gold-bearing series of strata in South Africa.

The examples mentioned above dealt with ore directly or indirectly associated with magnetic anomalies. The usefulness of ground magnetometers is definitely not limited to such cases. In the mining districts of Canada, where most of the geological formations are upturned and concealed by glacial deposits, the main use of ground magnetometers is to outline geological structures and formations under the mantle of overburden. Because the structures associated with ore deposition are often minor ones that can seldom be outlined from an aeromagnetic map, a ground magnetometer is usually employed to locate potentially ore-bearing minor structures. Ground magnetometers are excellent geophysical instruments that have proved their worth in Canada for finding ore and detecting geological structures masked by overburden.

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Airborne Magnetometers

The airborne magnetometer is a rather complicated apparatus using electronic principles to measure the variations in the total intensity of the earth's magnetic field. Airborne magnetometers are somewhat more sensitive than ground magnetometers, and surveys can be made more rapidly with them. The fluxgate airborne magnetometer was developed during World War II as a submarine detector, and in this it was eminently successful. With the close of the war no time was lost in applying the technique, with certain modifications, to exploration for petroleum and, soon, to the search for other minerals. At present there are four basically different types of magnetometers being used in aeromagnetic surveys — the fluxgate, electron beam, proton precession, and optical absorption magnetometers — all of which measure the total intensity of the earth's magnetic field.

Aeromagnetic Surveys

Magnetic profiles are flown along predetermined flight lines spaced according to geological requirements (in



NAE GS 6088

Plate 59A. A modern aeromagnetic survey aircraft used by the Geological Survey of Canada. It has a high resolution magnetometer mounted in the "stinger" which extends from the tail of the aircraft.



200099A

Plate 59B. Airborne magnetometer for use from helicopter (courtesy A. Aho).

general, at right angles to the regional strike of formations) and at a specified height, usually between 300 and 1,000 feet. A continuous strip of the ground below is photographed from the aircraft at the same time, to permit the various magnetic profiles obtained to be located later on a map. Before being plotted, the profile must undergo corrections for a number of disturbing factors, such as the daily variations in the earth's magnetic field. A separate stationary instrument is operated at a base station in or near the area during the survey to record the daily variations and so that surveys may be halted during severe magnetic storms.

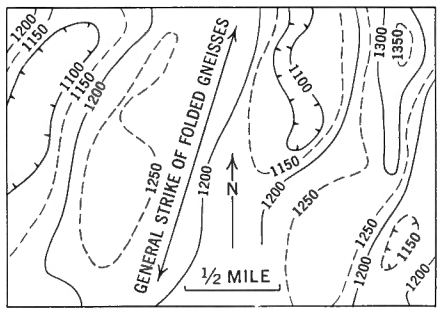
The corrected total field results are usually plotted as contour maps, because in this form they reveal information most readily. It is not uncommon to hear concern expressed regarding the accuracy of aeromagnetic maps. This results from failure to distinguish between accuracy and degree of detail. The modern airborne magnetometer is an extremely stable and sensitive instrument, capable of measuring differences in the earth's magnetic field of more than one part in 60,000. In this respect it surpasses the average ground instrument, but both have more than sufficient sensitivity and accuracy for their purposes. However, the airborne magnetometer is operated at an elevation of, say, 1,000 feet, and therefore responds to the magnetic influence of geological conditions over a fairly wide area below at any given instant. For example, two adjacent anomalies that might be well defined by a ground magnetometer survey may appear as a single combined anomaly on the aeromagnetic map. The lack of detail due to the height of the instrument above the ground is offset to some extent because a continuous profile is recorded, whereas the ground data are point measurements. In compiling an aeromagnetic map, an arbitrary magnetic-field level, greater than zero, is chosen so that all contour values will be positive.

Since 1947, the Geological Survey of Canada has published more than 4,000 aeromagnetic maps of many parts of the country, and more are constantly being issued. Each covers about 375 square miles, so that a considerable total area has now been surveyed. Most of these maps have resulted from aeromagnetic surveys carried out under a co-operative agreement between the federal and various provincial governments. Numerous mining companies also carry out aeromagnetic surveys under contract with aerial survey companies, and several exploration companies operate their own equipment. Such private surveys may be made in areas for which government maps are not available, or in favourable areas where more detailed surveys are wanted. Combined electromagnetic-aeromagnetic surveys are commonly made simultaneously with one aircraft.

In time most geologically promising areas will probably be surveyed with the airborne magnetometer. The Canadian prospector or geologist, faced with finding deposits that are increasingly difficult to discover, cannot afford to overlook any possible source of assistance, and for this reason, if no other, he must acquaint himself with the limitations of aeromagnetic surveys. Magnetic anomalies caused by magnetic minerals or variations of the magnetic properties or rocks diminish rapidly with distance from the source. Therefore, aeromagnetic surveys, because they are flown at a height of several hundred feet, show only the largest features of the geology. The airborne magnetometer does not replace the ground magnetometer, and the aeromagnetic maps should actually lead to a more intensive use of follow-up magnetic surveys performed on the ground.

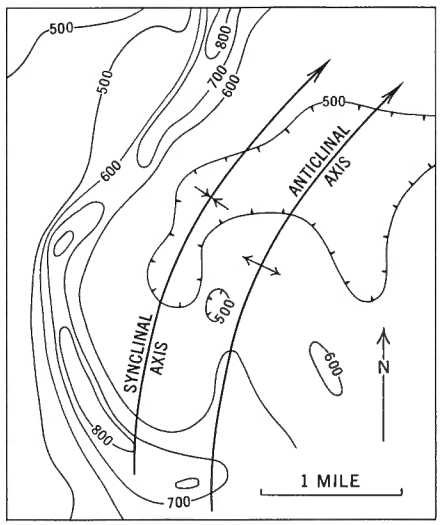
Interpretation of Aeromagnetic Maps

Although detailed interpretation of aeromagnetic maps is more within the realm of the specialist, a conventional prospector can gain much useful information from a personal study of these maps. This section presents a few



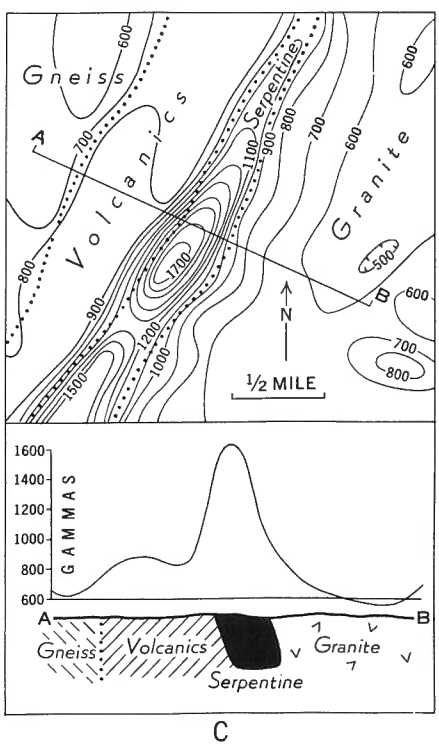
A

Despite the low magnetic relief of this area, aeromagnetic contours parallel the trend of steeply folded and contorted gneisses. The average strike is seen at a glance, but many ground observations would be required in this case to yield equivalent results.



B

A belt of relatively magnetic volcanic rocks is outlined by the aeromagnetic contours in the west half of the map. The double curve toward the south is related to known folding, as indicated by the fold axes. Recorded at a flying height of 500 feet.



C

A sharp anomaly produced by a sill-like body of serpentinized peridotite. The shoulder on the northwest side of the anomaly is caused by a belt of volcanic strata. The asymmetry of the profile is related to the southeast dip of the serpentine.

Figure 23
Diagrams illustrating interpretation of aeromagnetic data.

GSC

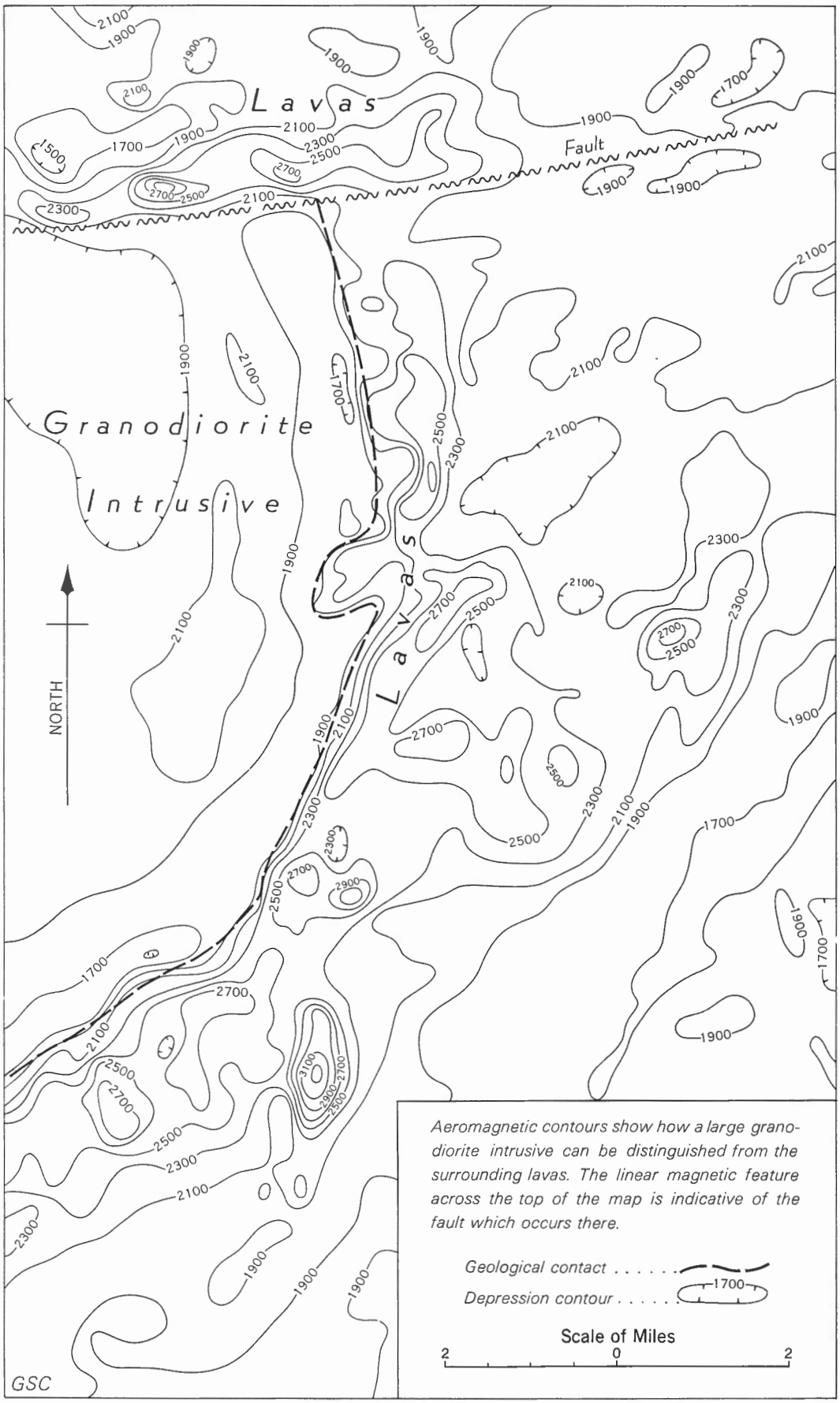


Figure 24
Aeromagnetic contours outlining a fault and a large granodiorite intrusion.

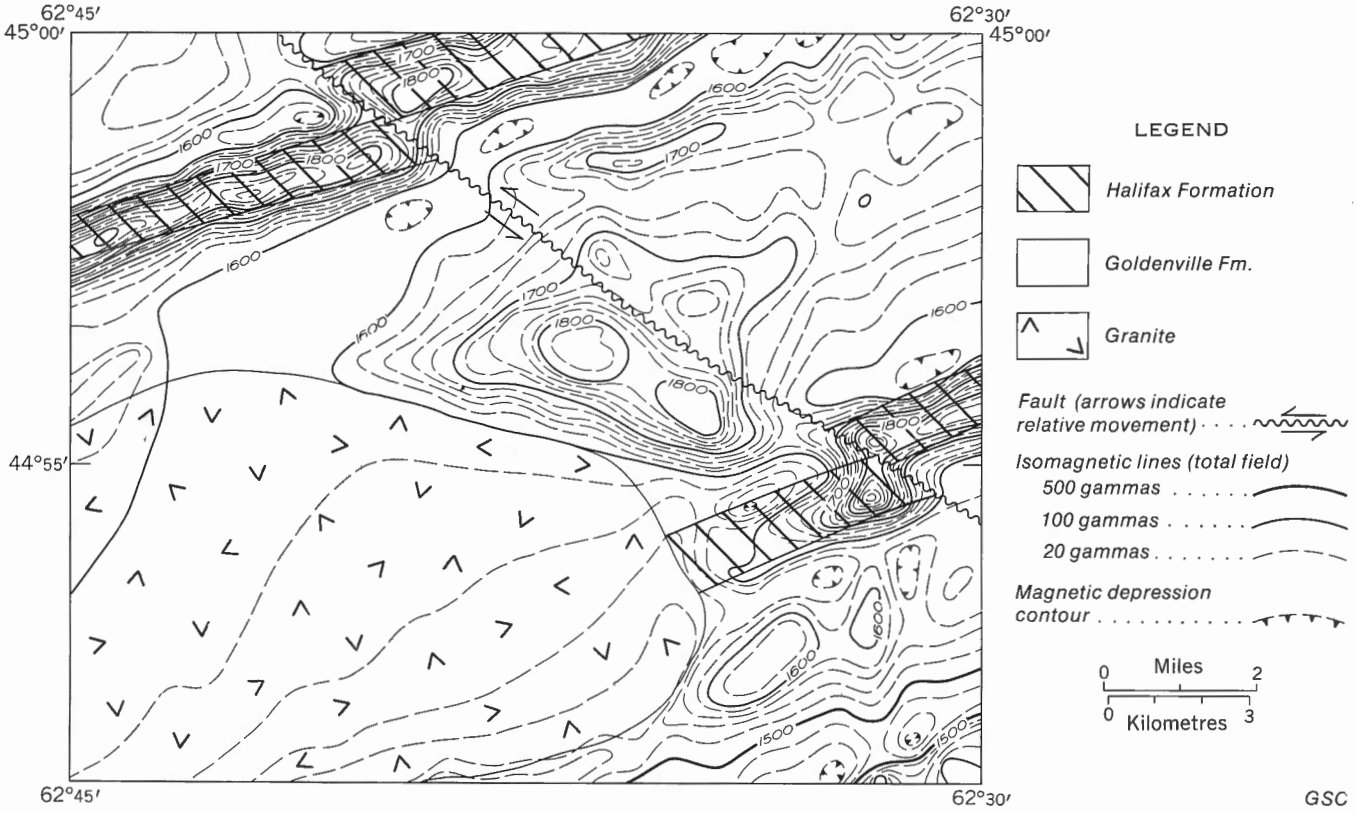


Figure 25. Example of the offsetting of magnetic contours due to horizontal displacement of a fault. Data from Aeromagnetic Map 7031G and Geological Map 592, Geol. Surv. Can.

factors that must be borne in mind when magnetic data are analyzed.

It is important to realize that the *amplitudes* (strengths) of nearly all magnetic anomalies are solely and directly related to differences in the magnetic content of mineral deposits or rocks. Magnetite is one of the most prevalent of accessory minerals, particularly in igneous and metamorphic rocks, so in some areas it is almost as remarkable to find no magnetic anomalies as to find many. Viewed in this light, an aeromagnetic anomaly in the Canadian Shield should be treated as just that, and, in the absence of further corroborative evidence, it should not be considered as representing the presence of a mineral deposit. Thus actual magnetic field values, such as the 'peaks' of anomalies, should not be compared as such with values from maps of another area. The intensity of an anomaly should always be expressed in terms of the deviation from the surrounding normal field, not in terms of the peak figure recorded on the map. The magnetic properties of rocks can generally be attributed to the presence of magnetite alone, so if a particular rock contains fairly uniformly distributed magnetite, the magnetic contours will directly indicate the positions of bodies of that type of rock.

Identification of Geological Units from Aeromagnetic Maps

If a geological map of at least part of an area being studied is available, as it usually is, the magnetic data corresponding to known geological units can be compared. The following points should be considered in relation to known geology: the maximum amplitude of the magnetic field over a particular rock unit; the shape of the anomaly (both of which are usually referred to jointly as the magnetic relief); and the pattern or texture of the anomalies on the magnetic map, which is governed by the trend, size, shape, spacing, and continuity of the individual anomalies. Areas of similar magnetic relief and texture, especially where they are on strike with known units, may then be interpreted as the same type of rock. Thus the detection of a geological unit usually requires that: the unit should have magnetic properties distinct from adjacent units; the contacts should be relatively sharp and, because a magnetic map provides a three-dimensional effect, they should dip fairly steeply. To be detectable a geological unit must generally have certain minimum dimensions which depend partly on the flight elevation, the spacing of flight lines, and the minimum contour interval used for the aeromagnetic map. Actually the reading recorded by the magnetometer would be the same as if the material between the magnetometer and the causative magnetic rock unit were stripped away. Thus the 'penetration' of magnetic measurements is unlimited, in contrast to the radioactive method, and a magnetic map is therefore somewhat analogous to an X-ray photograph. In an area where few or no direct geological observations are possible because of overburden rock types can commonly be interpreted in a general way from an

aeromagnetic survey. Great caution must be exercised, however, for the magnetic properties of many rocks are difficult to interpret. The following data may be helpful.

Sedimentary rocks. Sediments are usually very weakly magnetic, and therefore aeromagnetic surveys over sedimentary rocks show mainly anomalies due to the underlying igneous basement rocks. The greater the thickness of the sedimentary rocks, the more widely spaced will be the magnetic contours. Thus smoothness of magnetic relief is an indication of the thickness of the sedimentary rocks.

Igneous rocks in general. Igneous rocks have greatly variable magnetic properties (*see* Fig. 23). As a rule the acidic types tend to be weakly magnetic and the more basic types to be more strongly magnetic, because of their higher magnetite content.

Plutonic rocks. Granites are often inert magnetically, but with decreasing quartz content the magnetic properties tend to increase, so some syenites are commonly fairly magnetic. Gabbros are usually fairly magnetic and produce oval-shaped areas or irregular magnetic patterns; some gabbros however have rather low magnetic properties. Ultrabasic rocks, particularly the younger ones, usually have the most pronounced magnetic properties. Diabase dykes are often easily recognizable because they produce long narrow anomalies that may extend many miles.

Volcanic rocks. The basic types of lava tend to be more strongly magnetic than acidic types, and their magnetic pattern is much more irregular. Figure 24 illustrates a body of granodiorite abutting against more magnetic lavas so that the contact is readily apparent. Note that a magnetic halo has been formed in the lavas by the plutonic rock, a condition that is often a good clue to the presence of a plutonic body.

Metamorphic rocks. These also have somewhat variable magnetic properties. Direction of foliation is commonly indicated by parallelism of the associated magnetic anomalies.

Exceptions to the foregoing generalizations are so numerous that experience tends to discourage their use. For example, a highly magnetic sedimentary iron-formation may occur in an entirely sedimentary series; acidic lavas may locally be very magnetic; diabase dykes may be no more strongly magnetic than adjacent sandstone; granite in some areas causes huge, positive anomalies; some serpentine is virtually non-magnetic; and gabbro sills may exhibit striking lineation, both geologically and magnetically.

Structural Determinations from Aeromagnetic Maps

The importance of structural features in connection with conventional and advanced prospecting has been discussed in previous chapters. In regional structural mapping the geologist ordinarily pieces together information obtained on the ground or from air photographs, until a structural pattern is obtained on the basis of such evidence. Years of work may be required to gain an understanding of the regional structure by such means. Airborne magnetometer results may, in contrast, yield much information concerning large-scale structural features in a very short time, and they may supply evidence of smaller structures of importance in localizing mineral deposits. Aeromagnetic data should always be studied in conjunction with air photographs and any geological maps available when structural interpretation is undertaken; the combined data are admirably suited to the delineation of large-scale structures, particularly when the interpretation is done by a geologist familiar with such work.

Contacts. At high magnetic latitudes a steeply dipping contact between rock units having contrasting magnetic properties will be outlined fairly well by the point on a profile where the tangent to the profile has greatest slope. This is usually called the inflection point of the curve, and this rule-of-thumb is most accurate for shallow-buried vertical contacts and where the dip of the earth's magnetic field is also vertical. Where the unit is deeply buried the inflection points fall outside the contacts.

Strike. Magnetic contours commonly follow the strike of the underlying units as indicated on Figure 25. The strike direction may therefore be obtained by drawing a line through the longer dimension of the magnetic anomaly.

Dip. For a tabular body such as a dyke, the general direction of dip may be deduced from the asymmetry of the magnetic anomaly (*see* Fig. 25). Thus a tabular body dips toward the side of the anomaly having the least slope. Tilted or folded series of stratified rocks, particularly those that contain volcanic members, may also give rise to linear magnetic trends.

Faults. Faults are often recognizable by an abrupt change or dislocation in the magnetic contours. The right or left hand nature and amplitude of any horizontal displacement can commonly be measured, especially if a linear feature such as a dyke has been offset (*see* Fig. 25). If the horizontal displacement is small, the presence of a fault may be indicated only by inflections in the magnetic contours, which extend over a significant distance. If this lineation is parallel to the flight line direction it may have been produced by slight inaccuracies in navigation. A recommended procedure is to ascertain whether any surface expression of the fault also appears on air photographs. The vertical displacement of a dyke by a fault will cause the down-dropped side to produce an anomaly of lower amplitude, but one of slightly greater width. Thus the "sharpness" of a given anomaly is an indication of the depth of the causative body.

The geological interpreter should be thoroughly aware of the dangers attending 'blind' interpretation, (i.e., interpretation where no geological data are available). He should always indicate the degree to which his interpretation has been controlled by geological facts, and should make every effort to consider all these facts in his work. However when no geological information is available, he must do without it, with the expectation that some of the interpretations will be correct but that many will require re-interpretation in the light of subsequent geological observations. If possible, degrees of certainty should be indicated in some way on maps and in reports.

To conclude, aeromagnetic maps provide one of the most valuable means for securing information on the all-too-numerous regions that have not yet been geologically

mapped or have been mapped inadequately. Their prime purpose is to help to complete the geological understanding of these areas. Then with a more accurate and more detailed conception of the geological conditions in outcrops and under drift-covered areas, a prospector or geologist will have surmounted a substantial part of the handicap arising from the lack of outcrops or the lag in geological mapping.

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SEISMIC METHODS

by George D. Hobson

Seismic prospecting methods depend fundamentally upon the spreading or 'propagation' of seismic waves within rocks that are elastic to some extent. The 'elastic' waves generated by man-made explosions travel downward in all directions according to physical laws similar to those of optical theory. These waves are reflected and refracted at *interfaces* at depth and returned to the surface of the earth, where they are recorded. An interface is a surface between two geological bodies, generally two strata, whose physical properties are sufficiently different to cause detectable differences in the behaviour of the waves. This behaviour is called the 'acoustic' property of the strata or other bodies. The interpretation of recorded seismic data consists of determining the velocity of propagation of these elastic waves and analyzing the refraction and reflection phenomena that took place at the interface. Regardless of whether a *refraction* or a *reflection* seismic survey is being made, the quantity observed and recorded at each location is the time interval between the initiation of the elastic waves by an explosion or hammer blow and the first and later disturbances of the ground as detected by a seismometer at a known distance from the source of energy. Seismic methods have been used mainly in exploration for oil and natural gas and in engineering projects. Experiments in connection with mineral prospecting and the mapping of some Precambrian areas have shown promise.

Figure 26 shows a field layout and the time–distance graph related to it for a refraction seismic profile using a sledge hammer as a source of energy and a single-channel recorder to record seismic data. The proportion of the energy refracted is dependent upon the difference in propagation velocities on the opposite sides of the acoustic boundary. The basis of the refraction technique is Snell's Law and Huygen's Principle; the successful application of the technique is dependent upon an increase in velocity with depth. A decrease in velocity within any segment of the section will not refract the energy along an interface for eventual refraction and return to a detector on surface, but will refract the energy downward or away from the ground surface until a layer that transmits energy at higher velocity is encountered. Such a velocity inversion or velocity decrease with depth yields data which, when interpreted, will indicate excessive determinations of depth to underlying interfaces. The intermediate layers between surface and any interface at depth must also have a greater than minimum thickness which is a function of depth and of the contrast between velocities within adjacent layers. If the layer is too thin, a refracted wave cannot be transmitted through it and, if the difference in velocity between adjacent layers is small, these differences are very difficult to detect by the refraction technique.

Seismic refraction theory for simple two and three layer cases is adequately discussed by Heiland (1940), Nettleton (1940), and Dobrin (1960). Computations of the depths to the various velocity interfaces are based upon either critical distance or intercept time and the pertinent velocities. The simple equations for the two-layer cases using critical distance and intercept times are as follows:

$$Z_o = \frac{X_c}{2} \cdot \sqrt{\frac{V_1 - V_o}{V_1 + V_o}} \quad \text{and} \quad Z_o = \frac{t_i}{2} \cdot \frac{V_o V_1}{\sqrt{V_1^2 - V_o^2}}$$

The general formula for any number of layers, represented by n + 1, is as follows:

$$Z_{n-1} = \frac{1}{2} \cdot \frac{V_{n-1} \cdot V_n}{\sqrt{V_n^2 - V_{n-1}^2}} \left\{ t_{i_n} - 2Z_o \cdot \frac{\sqrt{V_n^2 - V_o^2}}{V_o V_n} - 2Z_1 \cdot \frac{\sqrt{V_n^2 - V_1^2}}{V_1 V_n} - 2Z_{n-2} \cdot \frac{\sqrt{V_n^2 - V_{n-2}^2}}{V_{n-2} V_n} \right\}$$

where
Z = depth to discontinuity $= \sum_{o}^{n-1} Z$
n = last penetrated bed
V_n = velocity within last penetrated bed
t_{i_n} = intercept time of V_n

A graph of the time interval required for the energy to travel from source to detector, plotted against the distance between source and detector, permits a determination of the velocity of the energy wave through the various media penetrated. The velocity of the seismic wave is the inverse of the slope of the time–distance plot for the various segments of the graph.

In general the simple refraction problem consists of solutions for three interfaces. In most places a very low velocity layer at the surface, only a few feet thick, overlies a dry material, which overlies wet materials, which in turn overlie bedrock. The interface between the second and third layers is commonly correlatable with the water-table. Interpretation techniques have now been developed to a degree that the various kinds of overburden such as sand, clay, and till can be distinguished one from another on the basis of the velocity of seismic waves through them. Kinds of bedrock can frequently be determined by the seismic velocities peculiar to different rock types.

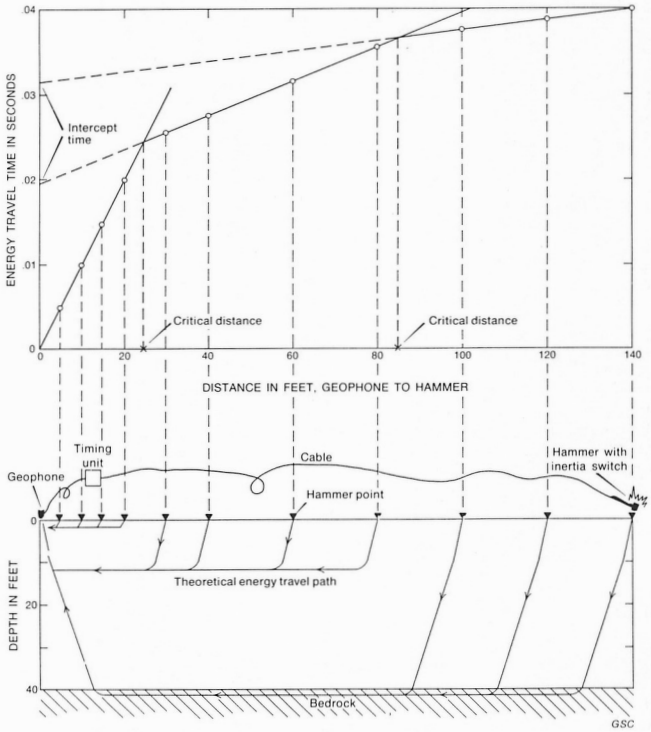

Figure 26. Typical hammer point spacing and time distance graph (after G. D. Hobson).

The reflection seismic method is illustrated on Figure 27. Note that the seismic wave does not cross the boundary between two adjacent media with different acoustic properties but merely meets that acoustic boundary and is reflected in the same way as light is reflected from a mirror. The fundamental physical law that the angle of incidence equals the angle of reflection holds as in optics. In this application, vertical velocities must be known or estimated so that depth determinations may be made from the observed data. It must be remembered that the time interval recorded is a two-way time; the energy travels from a source downward to a reflecting surface and then upwards to the detector on the surface.

In general, two types of instruments may be used to conduct seismic surveys: conventional oil prospecting instruments with twelve or twenty-four channels of data complete with magnetic tape for recording, all mounted on a truck, or light-weight very portable single channel instruments. The former may require a crew of eighteen men if drills are required for explosive shot-holes, whereas the latter instrument may be operated very efficiently by two men using a sledge hammer struck against a steel plate on the ground as a source of energy. The latter equipment has become very popular during the last ten years. Such an instrument is shown in Plate 60A.

Hammer seismograph instruments have been used frequently to locate diamond-drill sites where overburden was thinnest, and they should be useful as a preliminary step in large trenching projects. Without such information many drill contracts have required expenditure of all available funds merely penetrating the overburden whereas a brief



Plate 60A. A portable seismograph (courtesy Gilbert A. Milne and Co. Ltd.).



P. J. Hood 121899

Plate 60B. Conducting a hammer-seismic survey. Most striking stations are farther from the recording station.



P. J. Hood 121898

Plate 60C. Using a modern gravity meter.

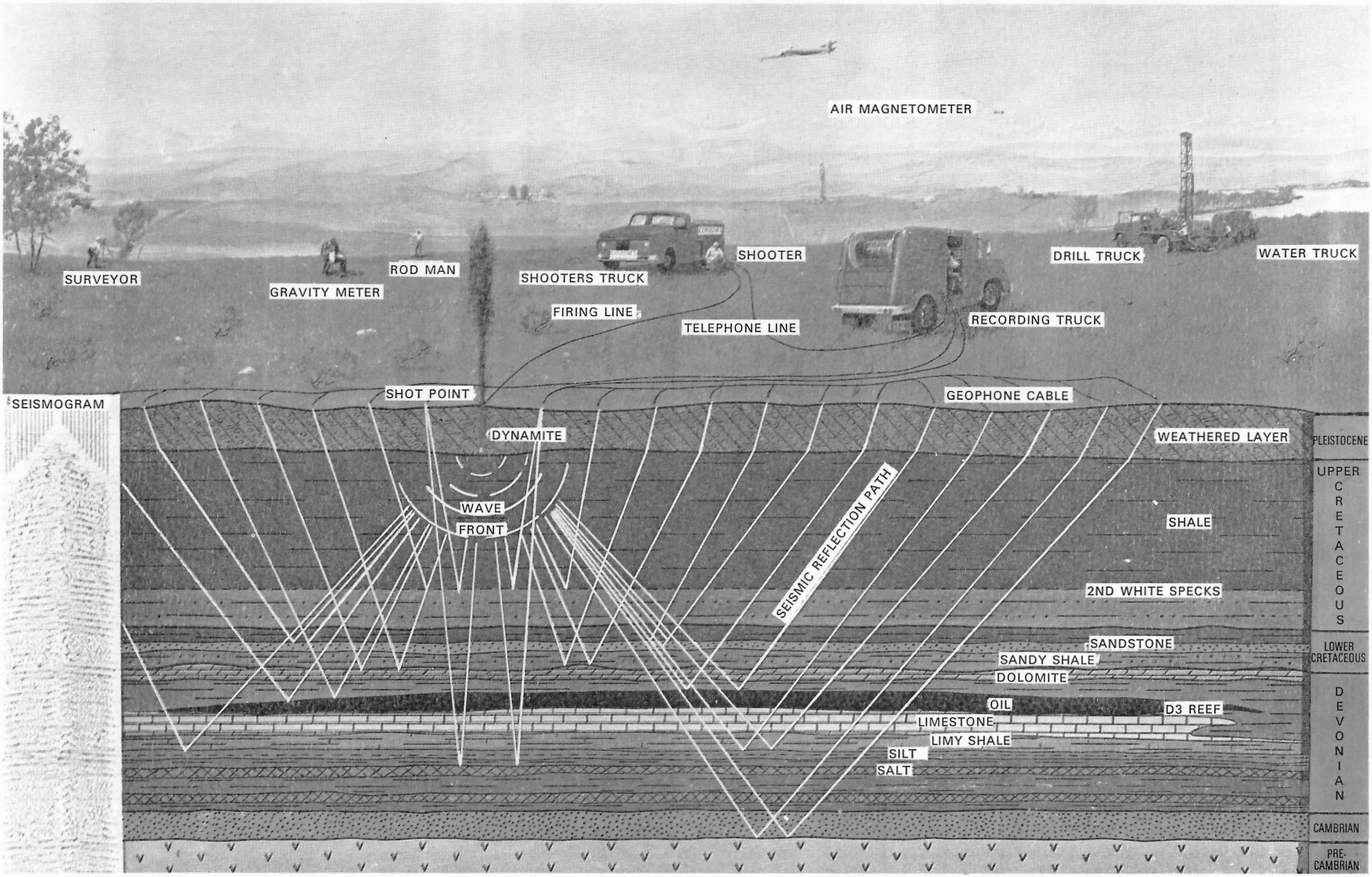

Figure 27. Imaginary illustration of seismic methods, showing blasting and recording equipment and seismic waves. Seismograms are included at left, and stratigraphic units at right.

seismic survey would have indicated more suitable sites. In many cases a drill site can be altered as much as a few hundred feet without rendering the objective impossible. The highly portable hammer seismograph can, in general, readily define drift thickness of 200 feet and has been successful to depths of 350 feet without resorting to explosives. Bedrock channels can be delineated by the seismograph, (Hobson, 1962, 1964); in some cases changes in types of bedrock can be indicated and in all cases velocities can be correlated with types of overburden. These bedrock channels frequently contain deposits of sand and gravel excellent as groundwater aquifers, and in some cases they may be repositories of valuable heavy minerals. Bedrock channels have been delineated in the Kirkland Lake area of Ontario, (Hobson and Lee, 1967). Seismic methods have also been used to outline the bedrock topography at some of the placer-bearing streams of the Yukon, where gravel and muck are permanently frozen (Hobson, 1966).

Shallow seismic techniques are also being used as an adjunct to biogeochemical surveys, (Fortescue and Hornbrook, 1967). The prospector must be aware of the thickness and type of overburden through which the various minerals have percolated to reach the roots of the trees examined in this developing prospecting technique.

Data available so far appear to indicate that acidic and basic rocks transmit seismic waves with different velocities, and that seismic energy travels faster through basic rocks than through acidic. In the Kirkland Lake area such energy is transmitted through acidic rocks with a velocity varying between 13,500 and 17,400 ft/sec while similar energy passes through basic rocks with a velocity ranging between 15,400 and 20,900 ft/sec. An overlap of these two velocity ranges appears to exist. This fundamental knowledge and application may assist an exploration program. A geologist may be concerned with distinguishing basic and acidic rocks at a prospect where outcrops are scarce and where seismic methods might apply.

Proterozoic sedimentary basins within the Precambrian Shield should be definable by seismic methods. Such areas as the Blind River uranium field of Ontario and the Athabasca sandstone area of northern Saskatchewan are examples. Conventional seismic instruments rather than portable hammer seismographs may be necessary because of the depths at which information is desired. Seismic research programs have been undertaken in both areas; the data is under review and interpretation at the time of writing.

Other structural problems can perhaps be resolved by application of the seismic method. A reflection seismic survey in the Cobalt camp using a hammer seismograph has had mixed success. Some definite observations were made, however; acoustic boundaries and reflecting interfaces exist between the Cobalt conglomerate and the Nipissing diabase, and between the Cobalt conglomerate and the Keewatin volcanics but no such definite seismically detectable interface was found between the Nipissing and Keewatin rocks. Improvements in instrumentation and modified field techniques would probably assist silver prospecting in the Cobalt camp, where some authorities consider the deposition of silver to have been controlled structurally.

The seismic method has thus been applied to several and varied problems in mineral prospecting and Precambrian mapping, but the full potential of the method has probably not been realized or even appreciated. Only a little imagination and application are required to develop new uses for the technique. For example, extensions of faults should be traceable under overburden or beneath the waters of a lake if the rocks have suitable properties. Experiments could be carried out in underground drifts, investigations being directed in an upward, downward, or sideways direction dependent upon whether the detectors were placed in the roof, floor, or wall of the drift. Gendzwill (1966) has applied the upside-down seismic technique to a problem in potash mining in Saskatchewan with considerable success. Faults could possibly be traced from underground locations provided that the fault was the interface between two media or rock masses with different acoustical properties. It may also be possible to define faults and structural phenomena by stringing seismic detectors in the walls of a mine shaft or in a drillhole and detonating explosives so as to record energy that has travelled and been refracted or reflected sideways.

The seismic approach has not been used extensively in the Canadian Shield, or other mining regions, but is potentially useful for locating certain structures favourable for mineralization. It is known that definite interfaces within the Shield can be detected and defined by the method. Geophysicists and geologists must abandon the traditional concepts that seismic exploration is carried out merely on the surface and that all observations are made downward. Only imagination and application are required to develop more novel approaches, because the equipment is available for the geophysicist, the geologist, and perhaps the fairly advanced conventional prospector to undertake seismic surveys. Traditional seismic field and interpretation techniques will apply in many cases and in others new solutions will have to be developed.

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GRAVITY METHODS

by George D. Hobson

Gravitational surveying today consists of measuring minute variations in the pull or attraction between a small mass and the earth. This pull is termed the force of gravity. Everyone is familiar with the action of this force. Sir Isaac Newton first stated the law governing the force of attraction in the year 1687. It may be stated thus: "Every particle of matter in the universe attracts every other particle with a force which is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them." This simply means that the closer two masses are to each other and the larger they are, the greater is the force between them. Each time we weigh ourselves we are actually measuring the gravitational force or attraction between ourselves and the earth. In fact, if a sensitive weighing device were employed, it would be possible to measure the attraction between ourselves and a nearby mountain.

The instruments used now for gravity surveys are capable of measuring extremely small differences in gravitational force. A good field instrument will measure to 1 part in 100,000,000; a massive sulphide orebody of 50,000 tons at a depth of 200 feet in greenstone would give rise to an anomaly of about 1/100,000,000 of the earth's total gravitational force and therefore is at the limit of detection. Lowering the height of the measuring instrument by one foot also will cause a difference of 1/100,000,000 in the measured force of gravity. As a force-measuring device, a gravity meter is therefore many times more sensitive than the finest chemical balance, and yet sufficiently rugged for field use. A single observation with it usually takes two or three minutes. One common type of gravity meter may be likened to a spring balance. With this type of instrument, a mass is suspended from a coiled spring; the amount of stretching of the spring depends upon the attraction between the earth and the mass. Minute variations in the length of the spring are measured by optical and mechanical devices. Readings of the extension of the spring are proportional to the force of gravity at the point of observation. These readings are usually expressed in terms of 'milligals'; one milligal is approximately equivalent to one millionth of the total gravitational force at the surface of the earth. As indicated above, a good field instrument will measure to within an accuracy of about one-hundredth of a milligal.

Any subsurface structure of higher density than its surroundings will exert an extra gravitational pull that will add to the earth's normal force of gravity in its vicinity. Suppose for instance there exists below the surface of the ground a large mass of very dense material such as a massive sulphide orebody, surrounded by rock of lesser density: because of the excess mass of the orebody, the force of gravity directly over it will be slightly greater than it will be to one side. The gravity meter measures only the vertical component of this 'extra' or anomalous force.

Thus a positive gravity anomaly, that is, a region of greater gravitational force, indicates material of higher density beneath the anomaly than that surrounding it. A negative anomaly on the other hand indicates material of lower density beneath the anomaly.

In common with many other geophysical surveys, a grid or series of lines is laid out to cover the expected geological formations or ore deposits. Before any inferences can be drawn as to the nature of the subsurface, certain corrections have to be applied to the readings taken in the field. In the first place, the instrument is so sensitive that it is affected by the position of the sun and the moon, so that the force of gravity at any particular point changes regularly throughout the day. This difficulty and the 'drift' due to instrumental changes during the day are overcome by occupying a base station at frequent intervals throughout the day during the course of the survey so that information is obtained for applying drift and diurnal corrections.

Corrections have to be applied for differences in elevation because the farther one is from the centre of the earth, the less the force of gravity becomes, as mentioned earlier. In order to make proper corrections, each point where the instrument is read has to be surveyed accurately for elevation. Because the earth is not quite spherical in shape, and because of its speed of rotation, the force of gravity increases as one goes north and a correction is applied for this by the accurate surveying of horizontal positions. Although the gravity meter measures only the vertical pull, it is nevertheless affected by the mass of surrounding hills and valleys and this effect must be eliminated through what are known as 'terrain corrections'. Thus it can be seen that a gravity survey involves more than merely reading the instrument.

It is true that the magnitude of the corrections far exceeds the actual measurements, but the error in making these corrections is so much less than the quantities measured that the final result, if properly computed, is perfectly valid.

It has been suggested above that the physical quantity actually measured by a gravity survey is the density of the underlying rocks and, that, in fact, a final gravity map is a picture of subsurface densities. The preparation of the gravity map is an exact science, and the knowledge, background, and skill of the geophysicist are required to interpret these results in geological terms.

The instrument is best applied in those cases where the material being sought is of high density and occurs in reasonably large masses. For instance, a hard, high-grade hematite is a dense material. Its massiveness is one of its outstanding physical characteristics. A gravity survey can disclose the presence of a concentration of hematite, and a fairly reliable estimate of the mass can be arrived at regardless of the shape, size, or distribution of the body. Such a survey can also be used to map structure, because many rock types are distinguished by differences in density. In general the basic rocks are more dense than the acidic. However, it must be pointed out that interpretation of structure on the basis of gravity data requires close geological control.

A large mass of lesser density near the earth's surface will give rise to the same observed gravitational phenomena as a smaller mass with a greater density at a greater depth.

Because of this, it is not possible to determine the exact position and shape of a mass causing an anomaly, but upper and lower limits to its depth can be determined. In this way, interpretation of gravity data is similar to interpretation of magnetic data. The depth limitation does not follow quite the same law and, generally speaking, it is possible to obtain useful gravity data from materials at greater depth than by most other methods. In fact, deep-seated heavy masses very often cause anomalies that can apparently obscure those relatively near the surface, which are usually the type caused by orebodies.

In summary, gravity anomalies are caused by any mass of material the density of which is different from that of the surrounding rock. Gravity surveys commonly supplement regional structural studies. A fairly large tonnage of dense material is required before an effect is detected, therefore the use of gravity methods for locating individual targets is most likely to be helpful in searching for massive base-metal deposits, such as hematite, massive sulphides, and magnetite, rather than for disseminated deposits.

Suggestions for Additional Reading

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RADIOACTIVITY METHODS

Principles

The basic principle of radioactivity was discovered in 1896 by Becquerel who noticed that a photographic plate had been accidentally exposed by a specimen of uranium ore placed upon it. Much research by Rutherford and others showed that this was caused by three kinds of rays (radiations) to which the names *alpha*, *beta*, and *gamma* were applied. This research also revealed that uranium ores are much more radioactive than the pure metal and led to the discovery of radium which, with its disintegration products, is strongly radioactive and occurs in all uranium ores in the ratio of 1 to about 3,000,000.

With the exceptions of potassium and rubidium, which are weakly radioactive, the normally occurring radioactive elements are the heavier ones having atomic weights of 210 or greater. The nuclei of their atoms contain so many particles that they are unstable and constantly decay to produce disintegration (daughter) products in the form of other, lighter elements or isotopes (atoms having the same chemical properties as the parent atoms but lighter nuclei and therefore different physical properties). The disintegration releases energy in the form of rays mentioned above.

An alpha ray is a particle four times as heavy as the hydrogen atom and carrying two positive electrical charges; when its charge becomes neutralized it becomes a helium atom. An alpha ray is stopped by a sheet of paper. A beta ray is an even smaller particle, its mass being about $\frac{1}{1800}$ that of a hydrogen atom. Beta rays are more powerful than alpha rays but are stopped by a thin sheet of metal. Gamma rays are not particles but powerful electromagnetic vibrations much like artificially produced X-rays, emitted as small 'bursts' of energy. They have various strengths and penetrating powers, commonly referred to as high-energy and low-energy or 'hard' and 'soft' radiations. Some are more powerful than X-rays but most are stopped by about 3 inches of lead, a foot of common rock, 4 feet of overburden, 2 feet of water, or 2 to 4 feet of snow depending on compaction and wetness. Gamma rays may penetrate several hundred feet of air and high-energy ones 1,000 feet or more. Radiations travel in all directions unless some are absorbed by naturally occurring substances or by artificial shielding. Because of the divergence of radiations from a small source they would be much fewer in a given area at increasing distances from the source, varying as the square of the distance, as illustrated by Figure 28.

Radiations of the kinds mentioned above cannot be felt or smelled, nor can they be heard or seen except indirectly with special instruments. The radiations from rocks, minerals, and ores are not known to be injurious to health, except that care must be taken not to breathe or swallow dust or small pieces and not to breath accumulations of the decay element 'radon' or its daughter products, which may accumulate in poorly ventilated mine workings. To be on the safe side, it is wise not to keep high-grade specimens close to the body for long periods and to scrub the hands and nails after handling radioactive material. Water near some deposits contains enough radioactive elements to affect a detecting instrument, in which case its drinking is not recommended. Mention should be made of some other misconceptions that were prevalent during the uranium boom. Radiation does not cause glowing in the dark, such as may be caused by phosphorescent wood, nor does it melt snow nor prevent water from freezing. It does not affect a compass or magnetometer, nor cause visible effects to plants or animals. It is of no known benefit to health. It cannot be detected in any 'mental' or hypnotic ways, by use of wands or other forms of dowsing, nor by any of the secret devices that have been investigated.

Equilibrium. Uranium and thorium are said to be in *equilibrium* with their daughter products when all are decaying at the same rate as that at which they are forming. If this condition is disturbed the element is said to be out of equilibrium or in *disequilibrium*. This may be caused by one or more daughter products being dissolved out

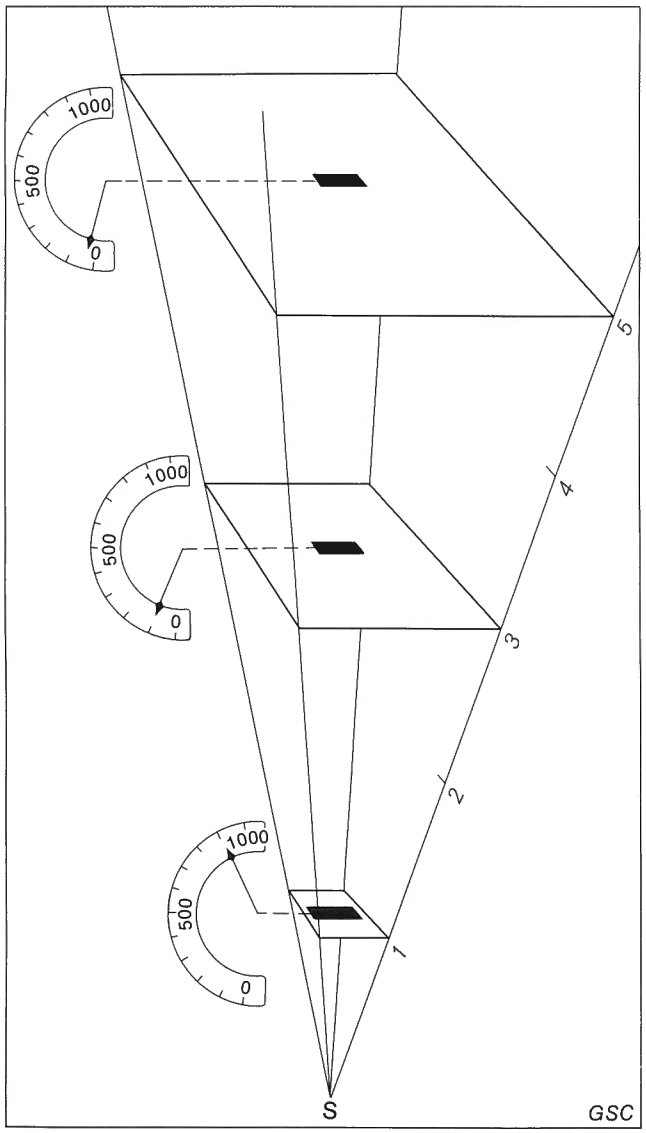


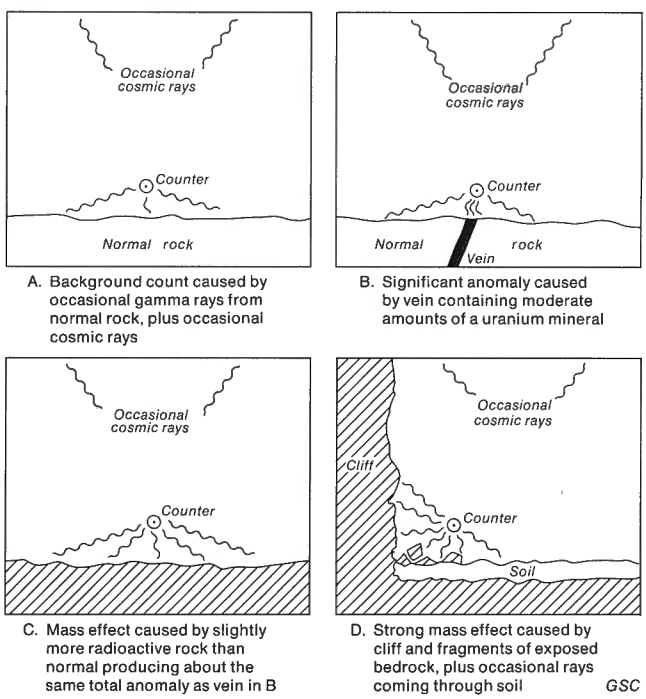
Figure 28. The diagram illustrates how the readings of a Geiger counter would be affected theoretically at varying distances from a very small point source of radiation, S, due to the operation of the inverse square law. Gamma rays from S radiate in all directions, as from the centre of a sphere, forming a sphere of radiation. The same rays that pass through the first square at unit distance 1 spread out into the larger squares at unit distances 3 and 5. The small black rectangles and dials represent a Geiger counter with its readings of 900, 100, and 36 counts per minute at distances 1, 3, and 5 units, respectively, from the Source S.

(leached) by solution, or by escape of a radioactive gas such as radon. Canadian supergene uranium minerals may not be old enough to be in equilibrium because most of them probably formed after glaciation ceased. Loss of radon and other gases may be caused by fracturing or alteration of radioactive minerals.

The question of equilibrium is not usually important in preliminary prospecting in Canada but it should be considered when judging the importance of a discovery. Ordinary laboratory equipment for assaying radiometrically for uranium is inaccurate if samples are out of equilibrium. Most laboratories now use 'equilibrium counters' that allow for disequilibrium, or other methods in which equilibrium is not a factor.

Uranium itself is not strongly radioactive. Most of the effect on a detector is caused by associated radon and radium. This fact may at times or in places cause abnormally high or low counts. Radon, which is a gas, may accumulate in cracks, pores in soil, or under a layer of clay, and so cause a high count when one of these conditions is disturbed and the radon is escaping. The count may be lower afterwards. On the other hand, it is theoretically possible that uranium, particularly when associated with sulphide minerals, may be dissolved and carried away in solution from an outcrop more readily than some daughter elements, so that an assay might indicate less uranium than was contained by the unaltered rock. These matters are not of great importance in most conventional prospecting but should be kept in mind.

Mass effect. All rocks emit gamma rays occasionally, because they contain minute amounts of radioactive elements, far too slight to be indicated by ordinary assay methods or to be recovered commercially. These rays, together with occasional cosmic rays, are responsible for what is called the *background count* (*see* Fig. 29). Many rocks emit more rays than this because they contain a little more radioactive material, which is commonly only a potassium-bearing mineral such as orthoclase, the common mineral in pink granite; others contain a few grains of a uranium or thorium mineral. These quantities are also below the possibilities of commercial extraction, but they may be sufficient to cause considerable anomalies when a detector is held near the rock, because rays emanating in



A. Background count caused by occasional gamma rays from normal rock, plus occasional cosmic rays

B. Significant anomaly caused by vein containing moderate amounts of a uranium mineral

C. Mass effect caused by slightly more radioactive rock than normal producing about the same total anomaly as vein in B

D. Strong mass effect caused by cliff and fragments of exposed bedrock, plus occasional rays coming through soil

Figure 29. Effects of radioactivity on a counter.

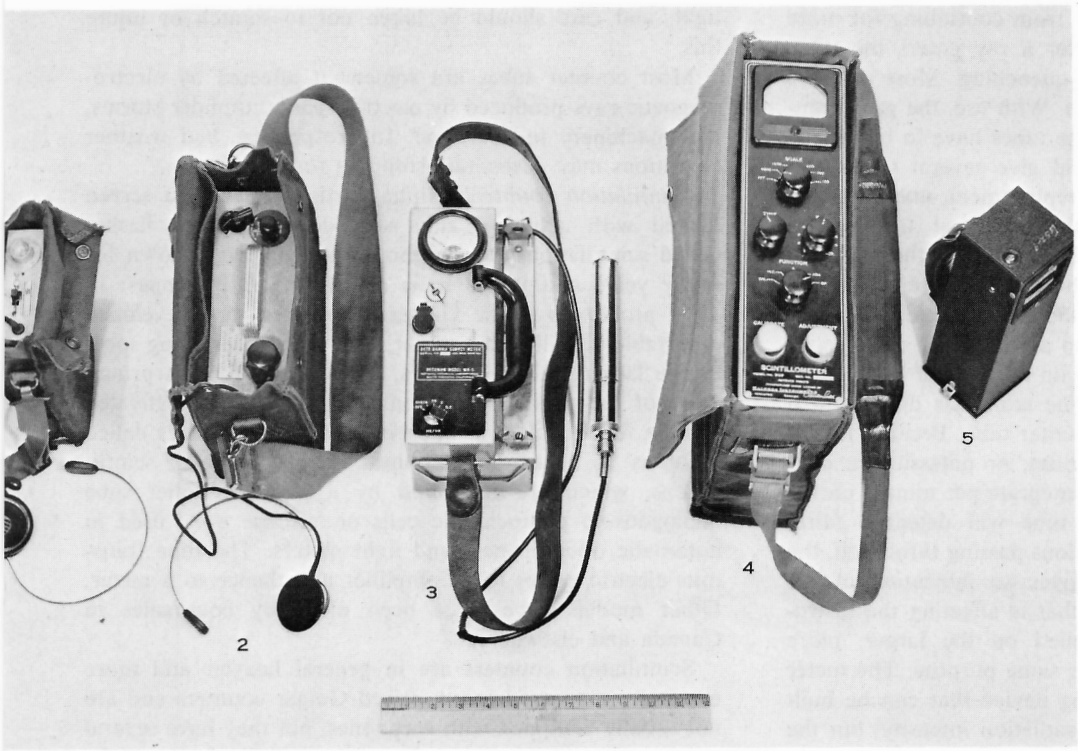
many directions from a mass of rock produce a combined effect on the instrument. The effect is increased if a probe is placed in a crevice; or if a detector is held near an overhang of such rock, because rays will be emanating from two planes; or if a detector is held near a cliff, because fragments of the weakly radioactive rock will probably be lying on the ground. The greatest mass effect is obtained in a cave or tunnel because rays originate from nearly all sides. Mass effect should always be suspected unless a uranium or thorium mineral is recognized. The effect can easily be confirmed by taking a few pieces of the rock, or a chip sample, together with the detector to a place where the background should be normal. Then place them on the ground or leave them with a companion, take the instrument a few feet farther, and after making sure that the background is normal, test the samples individually by holding each against the detector preferably as close as possible or in any other manner recommended by the instructions accompanying the instrument. In most cases the count will not rise significantly. If it does rise to 3 or 4 times the background the samples should be assayed, unless the operator finds from experience that the instrument or his way of using it requires a still higher count to yield significant assays. It is impossible to give more specific instruction regarding what might be a significant anomaly because a tiny high-grade veinlet might cause a strong anomaly but be worthless except as an indication of a possibly favourable area, whereas a large evenly mineralized body of rock carrying only 0.1 per cent uranium oxide might be valuable but cause only a moderate anomaly. The simple precaution of testing samples more or less on the spot is often overlooked, and has led to an incredible amount of misplaced optimism and waste of time and money on assays.

Radiation Detectors for Hand Use

Some publications discuss the use of electroscopes and scintilloscopes as aids in prospecting and mineral identification but these methods have now been superseded. The exposing of photographic plates or films by specimens has been virtually discontinued except for some laboratory uses; it might be helpful occasionally for a prospector in a remote area, who was without a detector or who had a defective one, if he were able to have the film developed. A high-grade specimen will in 24 hours produce an image on a film wrapped in light-proof paper, but a medium-grade one may require several days.

The detectors now used for most work on the ground are Geiger counters, scintillation counters and, to some extent, gamma-ray spectrometers, which were developed in this order and which in general are more complicated and costly in this order. Geiger and scintillation counters are manufactured in many different models at various prices (*see* Pl. 61). Encouraging results are being obtained with an experimental meter for detecting radon emanating from radium in rocks, soil, and water, which is being developed by the Geological Survey and Atomic Energy of Canada Limited.

Geiger counters. Geiger counters are based on a special tube invented in 1928 by Geiger (who had been associated with Rutherford) and which was modified by Muller. Geiger and Geiger-Muller tubes are slightly different and instruments containing one or the other formerly had dif-



E. C. Elliott 107328

Plate 61
Geiger and scintillation counters and a 'Mineral Light'. 1: small Geiger counter with earphone; 2: medium-size Geiger counter with earphone; 3: large Geiger counter equipped with meter and probe; 4: scintillation counter; 5: 'mineral light' or ultraviolet lamp.

ferent names, but today either is usually called a Geiger counter. The remainder of the circuits are much like those in radios. At first the counters were set up only for use in laboratories. In 1932 heavy, cumbersome portable forms were developed to search for radium lost at hospitals. About 1934 a set was made by the Geological Survey in Canada and used in the Bancroft region. This was the basis for roughly one hundred sets developed jointly and secretly with the National Research Council and made by the latter, during World War II and immediately after it. They were used by the Geological Survey and Eldorado Mining and Refining Limited, and some were supplied to other Commonwealth countries. When the period of secrecy was ended manufacture of counters based on these and on later developments was permitted. Geiger counters of other types were produced in other countries. Much of the weight and bulk is due to the batteries used to supply current to the Geiger tube and the amplifying tubes. The latter require low voltage current to heat their filaments, and are supplied by the A battery, which is exhausted fairly quickly when the instrument is in use as the amplifying tubes use full current whenever the instrument is in operation, whether weak or strong radioactive radiations are being tested. The high voltage supply delivers a current of about 1,000 volts (in some counters about 300) to the Geiger tube, and when only background or weak radiations are being received the drain on the B battery is relatively slight. Some detectors use only B batteries in series to build up the required high voltage for the Geiger tube; others use a smaller and relatively low-voltage B battery associated with a vibrator circuit, which delivers the required voltage.

A Geiger tube is filled with a mixture of gases under low pressure, the function of which is to prevent high voltage discharge between the electrodes from continuing for more than a fraction of a second after a ray enters the tube. This repressive action is called quenching. Most portable counters use self-quenching tubes. With use, the gas gradually becomes decomposed and the tubes have to be refilled or replaced, but the tubes should give several seasons of ordinary service before needing replacement, unless broken or otherwise damaged. Operating them at too high a voltage, if this is variable, tends to shorten their life. In operation, each passage of high voltage current between the electrodes of the counter tube is registered as a click on an earphone or helps build up a reading on a meter, or causes a light to flash, depending on the kind of instrument. Each click thus indicates that one atom has disintegrated and has been detected by the counter tube. Because in any given quantity of uranium, thorium, or potassium a definite percentage of the atoms disintegrate per minute on the average, and a given counter tube will detect a fairly constant percentage of the radiations passing through it, the number of clicks per minute gives an indication of the amount of radioactive element that is affecting the instrument. The meter that is supplied on the larger, more expensive, instruments serves the same purpose. The meter circuit is essentially an averaging device that can be built to react quickly to a change in radiation intensity, but the more quickly it reacts the more widely the needle will fluctuate, so that it would be difficult to take an average reading under such conditions. The longer the time during which the meter circuit builds up an average the steadier the needle will be and the more accurate the reading. In some instruments this time can be varied by a suitable control. Meters are usually connected with a switch by which they can be used to read three or more ranges of radiation intensity, usually increasing by factors of ten or more. Some meters on Geiger or scintillation counters indicate counts per minute (c/m) and others, milliroentgens per hour (mr/hr). A roentgen is a unit of radiation, named after the discoverer of X-rays. It is the quantity of X-radiation that produces one electrostatic unit in one cubic centimetre of air at standard temperature and pressure. Because radiation is emitted in separate bursts it must be defined as an average over a given time, commonly one minute or hour. As a roentgen is a powerful unit, detectors are generally designed to indicate milliroentgens (one-thousandth of a roentgen).

Some earlier types of counter tubes would not operate at low temperatures, and might have been erratic at high temperatures. Newer tubes are better in this respect, and will operate at zero or lower temperatures. If a counter is to be used in very cold weather it might be well to have assurance from the manufacturer that the counter tube will operate properly at low temperatures. Batteries also lose their efficiency with increasing cold, and may need to be insulated or kept warm. The usual effect of increased temperature on counter tubes is to increase slightly the number of counts received in a given time.

Most glass counter tubes are affected by light, and may register at a very high rate when exposed to light. Some tubes may have a black coating on the outside to exclude light, and care should be taken not to scratch or injure this.

Most counter tubes are somewhat affected by electromagnetic rays produced by electric sparks, thunder storms, and machinery in operation. In prospecting, bad weather conditions may necessitate stopping for a time.

Scintillation counters. Alpha particles striking a screen coated with activated zinc sulphide cause little flashes called scintillations; this phenomenon has been known for many years and is the basis of visual scintilloscopes. In 1949 professors at the University of Manitoba developed a portable scintillation counter, outwardly resembling some of the larger Geiger counters, by which radiations principally of the gamma type bombard a crystal of activated sodium iodide called a 'phosphor', causing particles called 'photons' to be emitted. Photons are the cause of scintillations, which are registered by a photomultiplier tube analogous to photoelectric cells or 'electric eyes' used in automatic door openers and light meters. The tube transmits electric pulses to an amplifier and thence to a meter. Other models have since been made by companies in Canada and elsewhere.

Scintillation counters are in general heavier and more expensive than moderately priced Geiger counters and are not usually equipped with earphones, but they have several advantages. They are much more sensitive because the

crystal reacts to many more gamma rays than does a Geiger tube. When dealing with low-grade deposits or making radiation surveys, or when endeavouring to detect through a maximum of natural shielding, they are estimated to permit recordings at 30 per cent greater depth of rock, snow, overburden, etc. than do Geiger counters. The need for registering background counts is eliminated because the proportion of rays from cosmic and normal rock sources is negligible. The phosphors do not wear out as commonly as Geiger tubes, but must be shock-mounted. Because gamma rays of different intensities form a *spectrum* or *flux*, instruments may be used to distinguish such intensities. Use of a formula then permits a closer estimate of uranium–thorium ratios than do Geiger counters with thin-walled window tubes. The formula and method of use are explained in pamphlets supplied with some instruments. Estimates made in this way are rather complicated and time-consuming.

Gamma-ray spectrometers. Some scintillation counters can be used in the way mentioned above to measure the different intensities (parts of a spectrum) of gamma rays and thus to distinguish between rays from uranium, thorium, or potassium. Electronic equipment that, in effect, eliminates the need for calculation has been used for some time together with scintillation crystals for laboratory and drillhole use. This has recently been developed in more portable forms which use larger crystals than the one in ordinary scintillation counters, as well as other equipment, to provide greater sensitivity and selectivity. Such instruments are still in the early stages of development and are larger and much more expensive than ordinary scintillation counters. At present their usefulness for surface prospecting appears to be for specialized prospecting when detection through maximum amounts of rock, overburden, or snow is desired, and for unusually accurate radiation surveys.

Selection and Care of Detectors

Geiger counters of moderate price are satisfactory for most prospecting purposes. Experience has shown that the cheaper ones are most prone to go out of order and that some are even defective on delivery. The most expensive Geiger counter and other types of detectors are mainly required by professionals, though not always. In selecting a detector one should seek a balance between the intended use, weight, shape, cost, and reliability. For long trips, two moderately-priced identical instruments would be preferable to one expensive one, to increase the likelihood of having a serviceable one. Detectors are obtainable from dealers in scientific and surveying equipment as well as other persons, some of whom advertise in mining periodicals. Earphones are desirable for preliminary prospecting so that the operator can watch where he is going and look at rocks instead of at a dial. A meter-equipped instrument is almost essential for making radiation surveys. A carrying strap is useful to permit walking with the instrument as close to the ground as possible and for slinging the instrument over the shoulder when not in use. Canvas cases provide protection but add weight and permit contamination by mine water and radioactive dust near old trenches or dumps. Detectors should have gaskets around all openings to make them as waterproof as possible; some models contain a small sack of silica gel to absorb any moisture that may enter. Probes are useful for some purposes. Those with a window and sleeve to permit or exclude entrance of beta rays permit greater sensitivity and estimates of uranium–thorium ratios because the ratios of beta and gamma rays differ for the two elements. Lead shields to place over probes in order to reduce mass effect have been made but are so heavy that they have been little used in Canada. Waterproof probes are useful occasionally for testing water-filled trenches or stream beds.

A scintillation counter into which earphones could be plugged at times would be useful for ordinary prospecting. The great sensitivity of scintillation counters may be a disadvantage for use underground where mass effect is high. Many persons prefer Geiger or scintillation counters reading in mr/hr.

When purchasing a detector one should try to obtain one accompanied by instructions for general use and maintenance, or at least have the dealer explain these. A circuit diagram is useful in case it is necessary to have a radio-repairman or other technician make repairs. Spare batteries and Geiger tubes should be available but not carried each day.

Detectors are fairly rugged but should be handled carefully and padded for shipping; those not waterproofed should be protected from moisture. Some operators of the larger models, even when these are protected by a canvas case, place waxed paper on the bottom and sides of the case so that it can be set on wet ground. Wetting of the earphones should be avoided; in wet weather this danger can be minimized by tying a plastic bag around them. The instrument should not be overheated. Care should be taken to see that dust or larger fragments from radioactive minerals do not contaminate the instrument or its case. Waxed paper is useful for this reason as well as to prevent wetting. In general, instruments used for surface work should not be taken underground in high-grade uranium mines or into treatment plants for uranium ore. The instrument should not be switched on for any length of time if near a highly radioactive specimen or deposit, as this would shorten the life of tubes and batteries; care should be taken to see that the instrument is switched off when not in use for some time. Batteries should not be left in the instrument when it is shipped or stored for long periods because swelling, leakage, or corrosion may result. Most types of counter tubes may give very misleading results when they are nearly worn out; therefore, it may be necessary to have a tube replaced before it is completely dead. It would be advisable to have the tube replaced before beginning a long trip in a remote district or as soon as the instrument consistently showed abnormally high background counts. A detector should be checked to see that it is operating properly before setting out for the day. Failure to do so once resulted in sensational publicity and costly trips by examining personnel because a counter showed maximum count as soon as it was switched on, but these readings were not borne out by assays.

General Methods of Prospecting

The usual method of prospecting with a radiation detector is to cover at random, or by systematic traverses across the general trend of formations, an area containing rock outcrops or shallow overburden. Such an area may be chosen as favourable in a general way from a geological report or map or from a personal reconnaissance, or it may be tested as a strictly unknown possibility so far as the prospector is concerned.

The detector is switched on and allowed to warm for a minute or so. It is commonly switched off when one is crossing large patches of deep overburden but this may cause a thinly buried source to be overlooked and too much switching may drain the batteries more than if the switch were kept on for reasonable periods. The 'background' count or reading is noted at a place where there is no reason to suspect the presence of a radioactive occurrence, such as over a lake, or a road, or a sandy area; it should be noted every hour or so thereafter, particularly if a Geiger counter is being used. The prospector should walk slowly, keeping the instrument in the same relative position and as close to the ground as possible, and observe the rocks and signs of mineralization as he goes. Observations and directions of travel should be written in a notebook. Positions may be recognized and marked on an air photograph. If a count of two or three times the background is detected and mass effect is ruled out, as explained above, the count should be noted as an anomaly and a more careful search made of the vicinity in the hope of finding a higher count. If not, an inexperienced person or one with an unfamiliar instrument might well take one or more samples of the weakly anomalous rock and have them assayed, so that he can better decide what constitutes an anomaly worthy of consideration for that instrument and his way of using it. If he finds an anomaly of many times the background or a radioactive vein or other type of deposit, he should proceed as advised in the section on preliminary exploration of prospects in Chapter 14.

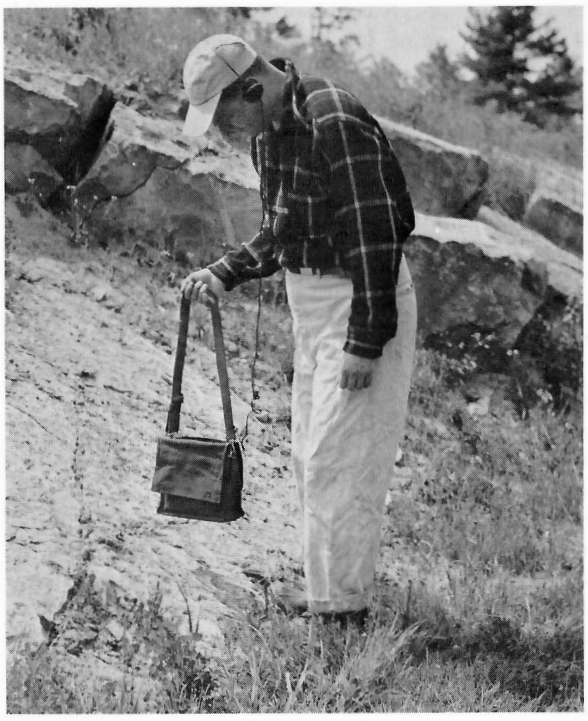
Ground Radiometric Surveys

Radiation or 'grid' surveys are useful for systematically prospecting a claim or group of claims or an anomalous area, as well as being an early step in the exploration of the vicinity of a discovery, particularly if the find is not clearly restricted to a single vein, dyke, or bed across a large outcrop or is not traceable from outcrop to outcrop. Such surveys should be made before any blasting is done as it causes scattering of radioactive fragments. Surveys may be undertaken by the prospector or an examining engineer or geologist, but as it is increasingly difficult to obtain an examination unless attractive sampling results and other supporting data are first provided, the importance of learning to make a preliminary survey is obvious.

To begin a survey a base line is established and cross-lines are surveyed unless they are to be run by pace and compass at the same time as the readings. Spacings may be from 500 to 5 feet depending on the size of the area to be covered and the time available. Common spacings are 400 feet for large preliminary surveys, 100 for slightly more detailed work, and 50 for fairly detailed. Readings (stations) are commonly spaced at shorter intervals than the spacing of the cross-lines. A convenient way of recording is on a piece of square-ruled paper carried on a clip-board, which eliminates the need for plotting later from a notebook. If two men are available one can hold an end of a tape and record the readings, and the other can move the required distance and call out the readings. If three men and two similar instruments are available, and stations are within calling distance, one can observe and call out readings while the third is moving to a new station and waiting for the needle to stabilize. Areas of outcrop and overburden should be indicated roughly and geological observations noted insofar as the prospector is capable. The instrument should be kept on between stations and abnormal 'spot' readings noted. The instrument should be placed on the ground, perhaps protected from moisture and contamination, in the same relative position at each station. If the ground is covered by mud or wet, the instrument may be protected by thin plastic or waxed paper and placed on two sticks carried for the purpose. Counters equipped only with earphones are useful solely for slightly anomalous areas because as soon as the rate becomes uncountable no further quantitative readings can be obtained. Readings are recorded in one of three ways: as the number of times (multiples of) the background count, as direct c/m or mr/hr, or as c/m or mr/hr less background. Recording multiples of background has some advantages if the plan is to be used by other persons, as it eliminates doubt as to what the background was or whether it was allowed for. Direct readings, preferably as mr/hr, are satisfactory if the initial background count and any variations are noted on the plan.

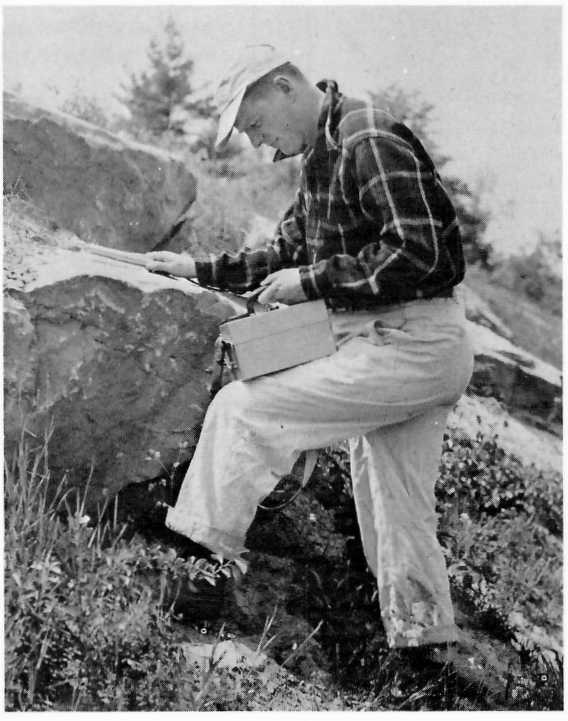
When the survey is completed the lowest and highest readings are noted and a suitable interval for the drawing of lines of more or less equal intensities (isorads) is selected. For example, if the readings ranged from 200 to 1,000 c/m, 200-interval isorads might be selected. Then, if the stations were plotted an inch apart and if the reading at station A was 230 and at B 310, it would be assumed that the 300 isorad would be about $\frac{1}{8}$ inch from B in the direction of A. Isorads, marked numerically in places, would be drawn until the plan resembles a topographic or aeromagnetic contour map (*see* Fig. 30). The location, type of instrument used, manner of counting, background count, scale, date, positions and numbers of specimens and samples, and the name of the person involved should be added to the plan. The areas enclosed by the highest or a few of the higher isorads are commonly surveyed at closer intervals than the first survey.

Radiation surveys are only semi-quantitative, because some of the deposit is almost always covered by a little rock or overburden that provides partial shielding. They must, therefore, always be supplemented by sampling. The Gunnar mine provides a good example of the usefulness of a radiation survey. Immediately after the discovery of strongly radioactive swampy ground containing a few angular pieces of radioactive rock, the two prospectors with



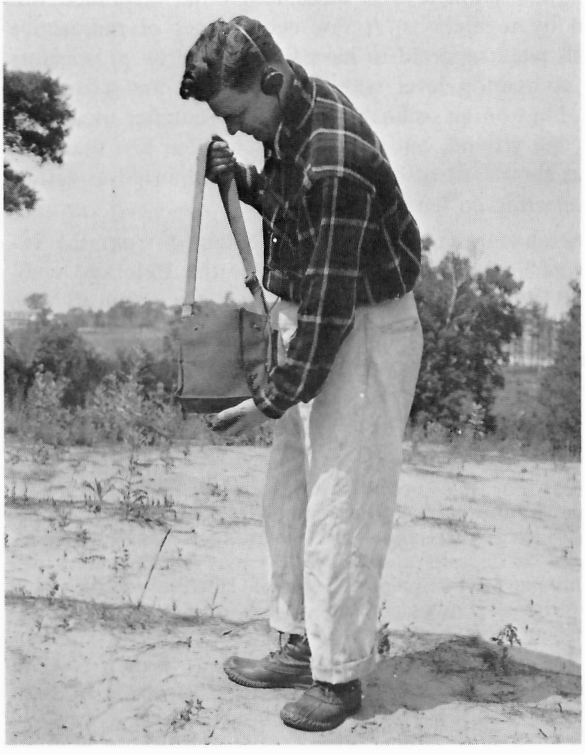
A. Using counter with earphones to test outcrop.

Plate 62
How to use a counter.

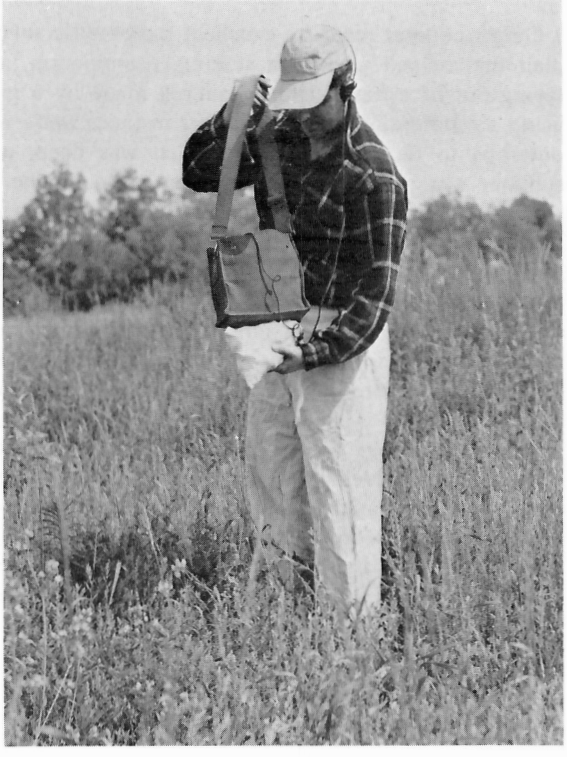


B. Using counter with probe to test outcrop.

C. Testing specimen, at a place where the background is normal.



D. Testing a sack containing a chip or channel sample, at a place where the background is normal.



Photos by A. H. Lang

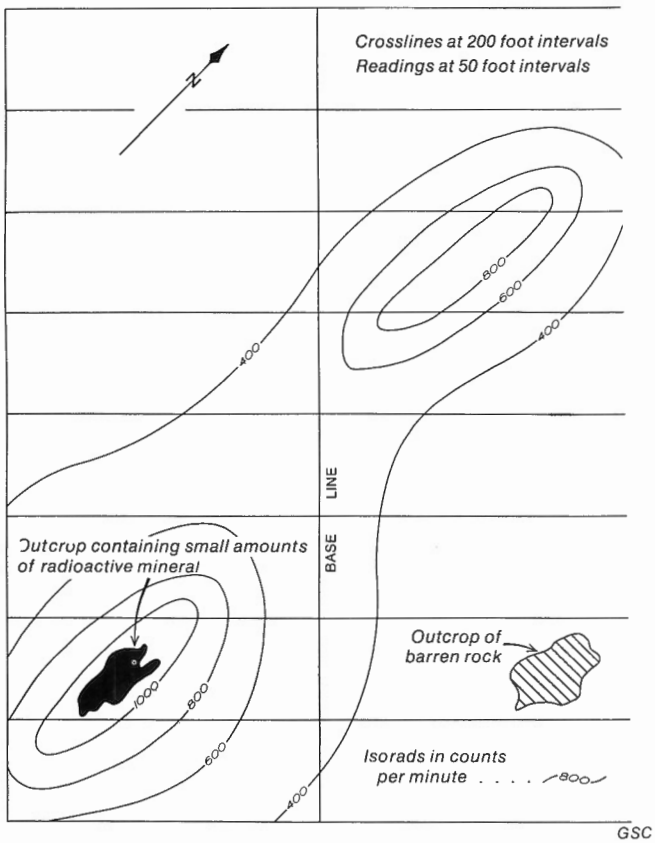


Figure 30. Example of simple radioactivity survey. The areas enclosed by the highest isorad would receive first attention in the form of sampling, stripping or trenching through overburden, or more detailed radioactivity surveys.

a Geiger counter made an excellent radiometric survey and plan that helped greatly in staking, examination, and the laying out of a more detailed survey made by a geologist using a scintillation counter. In this instance there were no outcrops to be sampled, overburden was deep, and the summer was nearly over, so drilling based on the second radiation survey was done during the following winter.

Reconnaissance radiation surveys have been made with a scintillation counter held beside an open window of a slowly moving automobile. A niobium deposit was reported to have been found in Canada by investigation of an indication obtained in this way. Special equipment has been mounted on automobiles and small railway vehicles, but places suitable for such surveys in Canada are limited. Equipment for logging drill-cores and drillholes radiometrically is highly developed. Logging of holes is desirable in areas where uranium minerals are distributed irregularly, and also where core recovery is unsatisfactory. Further information on Canadian logging equipment and practices is contained in "Canadian Deposits of Uranium and Thorium", pages 122–23.

Aeroradiometric Surveys

The possibility of detecting uranium deposits from aircraft was investigated eagerly in several countries when uranium became of great importance soon after World War II. Although some successes in other countries were reported and a few occurrences of radioactive minerals in Canada were reported to have been made by investigating indications obtained from aircraft, the results of extensive experimental surveys were mainly disappointing. This was chiefly because of lack of instruments that would adequately distinguish between gamma rays attributable to the presence of uranium, thorium, and potassium, and because high background counts and many anomalies were caused by mass effects from large bodies of rocks containing small quantities of those elements. More promising results are now being obtained from experimental surveys with gamma-ray spectrometers.

Experimental aeroradiometric surveys were begun in Canada in 1947 and continued until the temporary decline of emphasis on additional deposits of uranium. Various projects of Eldorado Mining and Refining Limited, the National Research Council, Atomic Energy of Canada Limited, and the Geological Survey of Canada were conducted jointly, and Eldorado made experimental scintillation surveys with a helicopter in 1953 and 1954. Geophysical firms, research groups, and private prospectors also made experimental and contract surveys with conventional aircraft and helicopters. Many anomalies were indicated by systematic surveys with conventional aircraft over many parts of the Canadian Shield but these did not result in significant discoveries. Apart from the general difficulties of resolution and of distinguishing anomalies representing uranium occurrences, many anomalies were found to be caused by flying over hills or ridges underlain by weakly radioactive rocks, during a period when use of radio-altimeters to measure ground clearance was banned by regulations. A few occurrences of radioactive minerals were reported to have been found by prospectors flying at tree-top level with light aircraft, and observing the readings on an ordinary scintillation counter meant for use on the ground, but such reports totalled less than ten, whereas thousands of occurrences were reported as results of prospecting on the ground.

More encouraging results were obtained from the experiments made by A.F. Gregory for the Eldorado company in 1953 and 1954, using a helicopter equipped with a specially built scintillation counter. Known deposits and general areas in northern Saskatchewan and Manitoba were covered by line and random flights, some observations being made by hovering. Gregory's conclusions (1955) were:

> (1) For the successful detection of undisturbed vein sources, the present Eldorado detector must pass within 150 feet of the source. Area sources such as sedimentary uranium deposits and pegmatites may be located at distances at least as great as 500 feet. However, at such high elevations, granites and other sheet sources also cause significant anomalies.
>
> (2) The relative success of various aerial radiation survey techniques depends upon the geological environment in which the desired sources are located.
>
> (3) Anomalies may result from a number of causes, of which only one is a potential orebody. As a consequence,

altitude control and source discrimination are required for successful and economical use of the technique.

(4) Evaluation of anomalies on the basis of signal to background ratios or similar means may or may not be a useful procedure, depending on the source sought and elevation flown.

(5) Low-elevation flight is necessary for efficient detection of localized sources in igneous and metamorphic complexes. Such flight emphasizes veins, points up sedimentary and pegmatitic sources, and discriminates against granite.

(6) Low-elevation helicopter exploration is a technique of high potential use not only for location of radioactive minerals but also for general mineral prospecting through recognition of gossans and other geological phenomena.

(7) Providing the required activity contrast is present, detailed aerial radiation surveys may be useful in the location of minerals which, in themselves, are not radioactive but which may be associated with radioactive material (*e.g.*, beryl, columbite, and similar minerals associated with pegmatite. It may be that beds of high-potash salts could be located on the basis of their K^{40} content.)

(8) There is a general correlation between rock type and the radiation intensity which may be useful as a reconnaissance geology technique.

(9) For each detector, there is a minimum area and grade relation for detection of a source at any one flight elevation. Those sources having area-grade factors below this minimum will not be detected.

(10) Aerial radiation detectors can locate surface radioactivity only.

(11) In view of (9) and (10), the fact that radioactive mineral deposits have not been located by aerial survey in any particular area does not indicate that such deposits are non-existent in that area.

(12) A random-flight survey will give better coverage at less cost than a line survey. The line survey, of course, gives greater detail.

(13) Since other detectors may have different sensitivities, it is suggested that all detectors should be evaluated in terms of the size of source which they will detect at various distances. The source used for calibration should, of course, have geological significance.

(14) The results of aerial radiation surveys should be interpreted with caution, especially in cases where the limitations of both technique and detector are not established.

Revival of interest in prospecting for uranium, and the development of gamma-ray spectrometers led to further aeroradiometric experiments during the last few years. Among these are tests made by A.G. Darnley of the Geological Survey of Canada, in the Elliot Lake and Bancroft areas, for which a preliminary account has been published. For ground control about 1000 measurements were taken on overburden and outcrops, on grids with 200-foot intervals. In both areas, radiations from outcrops and overburden were found to be approximately similar. A large helicopter carrying experimental equipment constructed by Atomic Energy of Canada Limited was used for flights at various spacings, heights, and speeds. Darnley's conclusions (1968) were:

> There are a few obvious precautions which should be taken in connection with an airborne radiometric survey. Firstly, there is no point in mounting elaborate and sensitive equipment in an aircraft to detect radioactivity if the aircraft itself contains radium-luminized instruments. Older aircraft commonly contain many instruments of this type. Furthermore if the radioactivity within the aircraft is checked when it is on the ground it may appear that the detectors can be placed sufficiently far away for them not to be affected by luminous dials. However, it should be remembered that what may appear as a trivial contribution to total background when on the ground may be a major contribution when in the air. Secondly, there is no point in looking for small variations in count rate if terrain clearance is not effectively monitored. A 50 ft change in terrain clearance will produce a 10% change in count rate from a large area source. For a small area source the change in count rate will be much more severe.
>
> Thirdly, the air background over water in the area of survey should be accurately determined at the beginning and end of every airborne sortie. Similarly instrument calibration must be checked at least at the beginning and end of every flight.
>
> Based on the 1967 field work there is encouraging evidence that many rock types, and rocks of different ages, will be found to yield characteristic spectral "signatures" that will enable them to be traced across country from the air. These signatures will be based on the distribution frequency of the potassium, uranium and thorium count rates. The Geological Survey's new airborne system is designed to have sufficient sensitivity to read these signatures. However, this type of geological mapping will only be possible if it is used in conjunction with photogeological interpretation to provide essential information about the position of boundaries of rock units. Photogeology can separate and correlate rock units more readily than it can identify them; radiometry will probably be able to identify many of them provided information is available as to where units begin and end. However, one thing is certain: that gamma-ray spectrometry is not by itself a panacea and even when used with other techniques the interpretation must, in the last analysis, be confirmed on the ground. Intelligent and expeditious application requires that complementary ground data be obtained in parallel with the airborne data before compilation and interpretation takes place.

Suggestions for Additional Reading

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ELECTRICAL METHODS

Electrical prospecting is the art of measuring electrical properties of rocks and mineral deposits in the part of the earth's crust that is within the reach of mining. Electrical methods, which are the most versatile and complex of all geophysical prospecting, are of two main kinds: those in which natural electrical fields are measured, and those in which a field of force is imposed by the geophysicist to suit a particular situation. Electrical methods include the self potential, resistivity, electromagnetic (inductive), induced polarization, and telluric current techniques.

Like some other geophysical techniques, electrical prospecting was conceived long ago, the elaborate instruments and carefully devised methods of today resulting from ideas that have evolved over the past two centuries. The earliest work in electrical prospecting appears to have been done by Gray and Wheeler in 1720 who made a study of the electrical properties of rocks and listed their conductivities. Watson in 1746 discovered that the ground is an electrical conductor. The next recorded work was done by a Cornish engineer, Robert W. Fox, in 1830. In the copper mines of Cornwall, he made the fundamental discovery that natural electrical currents are associated with sulphide ore deposits. To Fox also goes the credit for suggesting, in 1843, that the natures and textures of rock formations, the saline content of subterranean waters, and the proportions of sulphide minerals in rocks would affect their electrical conductivities. His discoveries stimulated much discussion and experimentation in England and Germany between 1830 and 1845. Fox was also apparently the first to postulate the existence of other natural currents called 'telluric' and their effects on the geomagnetic field.

Other studies concerning the origin of natural earth currents were made between 1847 and 1867 by A.C. Becquerel and Charles Matteucci. During the period between 1844 and 1882, research on the electrical activity of orebodies was apparently abandoned. In 1882, Carl Barus of the U.S. Geological Survey published his classic paper "On the electrical activity of ore bodies", which described his electrical measurements done on the Comstock lode and in the Eureka mining district, both in Nevada. He also realized that, if an orebody generates electrical currents, a self-potential anomaly may be found even though the electrodes do not actually touch the orebody.

In 1902, Alfred Williams, an Englishman, and Leo Daft, an American electrical engineer, patented a method in which a low frequency alternating current was sent into the ground by means of electrodes and the current distribution was studied by means of two separate search electrodes. They were troubled by serious difficulties due to induction effects between the transmitter and receiver. Conrad Schlumberger, who is perhaps the most colourful personality in the field of electrical prospecting, patented the direct current method in 1912.

The father of modern quantitative resistivity methods in the United States was Frank Wenner, a physicist at the U.S. Bureau of Standards. He introduced the concept of four in-line equally spaced electrodes that facilitated a simplified mathematical treatment and quantitative study of electrical resistivity.

Concurrently with the early electrical studies at the U.S. Bureau of Standards, H.R. Conklin, an electrical engineer, took out basic patents in 1917 on a high-frequency electromagnetic method in an attempt to find conducting sulphides (galena and pyrite) in the Tri-State zinc and lead district. His work constituted the first serious experiments with the electromagnetic method. His primary transmitting coil, a circular loop 200 feet in diameter, was laid on the ground; the electromagnetic field produced within the loop was measured by two small identical exploring coils that were balanced against each other in series opposition and were connected through a detector to a galvanometer. With one coil held stationary, the other was moved along a curve in such a way that the galvanometer reading remained zero. This idea is basic to practically all such methods today.

The phenomena of induced polarization was first mentioned in the literature by C. Schlumberger in 1920 who called it "provoked polarization". He measured the decay of secondary voltages in the earth after the interruption of the primary current. His conclusions were that polarization potentials were of a similar nature over sulphide-bearing and barren ground and so he abandoned any further investigations. It was not until 1947 that A.A. Brant, a Canadian geophysicist, began seriously investigating these induced polarization or overvoltage potentials for the detection of disseminated sulphides. Since that time many investigators have contributed to the induced polarization technique to make it the world-wide accepted geophysical prospecting tool for disseminated sulphide deposits.

The most recent advances in geophysical prospecting for sulphides have been in the use of natural earth fields. The method called AFMAG, a name coined from audio frequency magnetics, was first reported in the literature by S.H. Ward in 1958, a Canadian geophysicist, who was working on the method with American Metal Climax, Inc. and McPhar Geophysics Limited in Toronto since 1948. The chief source of energy is from lightning discharges originating in the tropical regions. Magnetic fields of all frequencies from 1 hertz (1 cycle per second) up to radio frequencies are propagated within the space formed by the ionosphere and the earth's surface. The method is similar to an electromagnetic system with the exception that the transmitter can be considered to be removed to infinity. The magnetotelluric method, first announced in France by Louis Cagniard, in 1953, involves comparison of the right-angled horizontal components of the magnetic and electric fields associated with the flow of low-frequency telluric currents in the earth. Recent work in 1967 by A. Becker and J.A. Slankis, Geological Survey of Canada, has shown that the magnetotelluric and telluric methods are applicable to mineral exploration for sulphide conductors. The telluric method has several advantages since it does not require a current source and the associated long leads; it combines flexibility, rapidity, and low cost; and it reaches much greater depths of penetration than do ordinary resistivity methods. The

magnetotelluric method offers the benefit of making possible, in most cases where the bedding is horizontal, a truly quantitative interpretation.

Self-Potential Method

In some methods of geophysical prospecting, advantage is taken of naturally occurring fields of force, as in the magnetic and gravitational techniques. In these cases, the geophysicist relies on the magnetic attraction or the gravitational pull inherent within a mineral body itself. Some other methods require him to employ special apparatus to generate an artificial field of force, so that he can measure the reactions of mineral bodies to such a force. The seismic and electrical methods are of this type. There is an electrical method that actually falls in the first category, however, and which relies upon observing electrical fields of force, that is, electrical currents, which are generated naturally by certain types of mineral bodies. This method is known as the spontaneous polarization or self-potential technique. The term 'spontaneous polarization', means that the particular mineral body spontaneously acquires an electrical polarity, that is, one end becomes electrically positive and the other negative; and 'self-potential' means that the mineral body itself generates an electrical potential or force.

This description of the technique is not intended to give directions for carrying out surveys by the spontaneous polarization method, or for interpreting the results. Both require experience. Its purpose is to furnish enough background information to enable the reader to gain some idea of how and where the method can be applied, of the significance of the results, and how data are assessed for their possible importance to an exploration program. The first question to arise is naturally "What types of deposits generate these spontaneous electrical currents?" Evidently such deposits act like electric batteries, which gives the clue to what the geological requirements must be. A battery, whether an ordinary flashlight cell or a storage battery, generates electric currents because one or more metallic substances are in contact with either acid or alkaline solutions. In the ground, the common sulphides provide the metallic element like that of the battery, and such sulphide bodies are in contact with mildly acid solutions at the surface, and with mildly alkaline ones at depth. The acidity of near-surface solutions may be due to humus and to carbon dioxide absorbed from the atmosphere, and may also be augmented by the oxidation of sulphides. Rock moisture at depth is usually alkaline from reaction with rock minerals.

These solutions in contact with the metallic conductor (sulphide body) generate a current that flows down the sulphide body to depth, passes out into the wall-rocks and returns to the surface, where it completes the circuit by flowing back into the apex of the sulphide body. Most metallic sulphides are conductors of electricity and can serve as the metallic element in such a natural battery. The only common exception is sphalerite, which does not have a metallic lustre, whereas most sulphides possessing metallic lustre are also conductors of electricity and can act as natural batteries. Even sphalerite may sometimes act weakly as a natural battery. In addition to the sulphides, there are some other minerals that act in the same manner to generate natural currents. Principal among these is graphite, but anthracite coal frequently serves to generate currents, and so do the manganese oxides: pyrolusite and psilomelane. The iron oxide, magnetite, does not always possess metallic lustre, is not a good conductor, and does not normally generate appreciable spontaneous polarization currents.

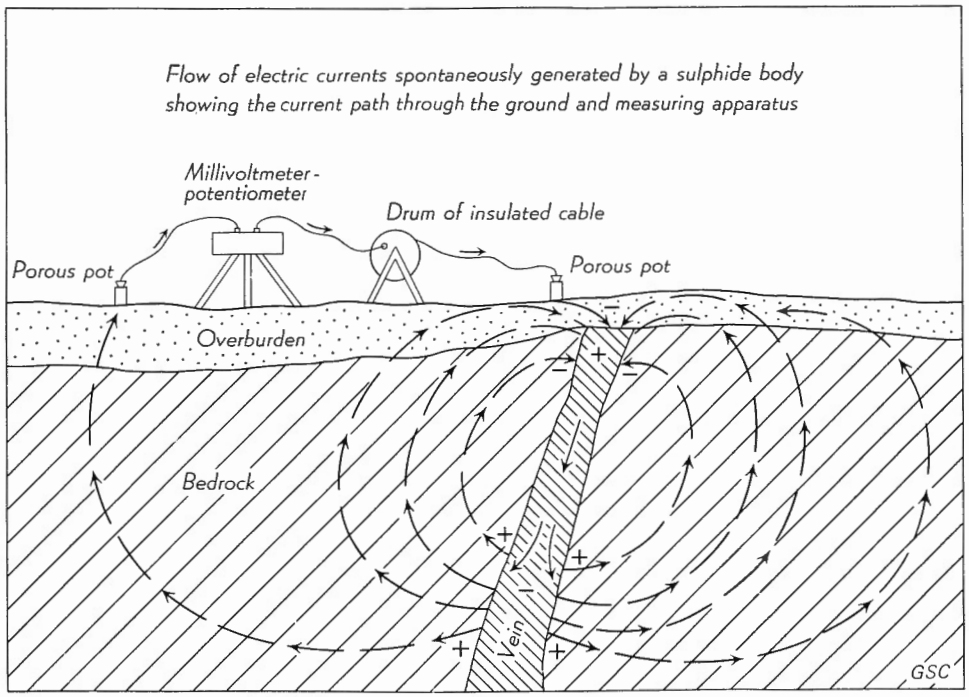

Figure 31
Illustration of the self-potential method.

Although the statement is occasionally made that these spontaneous currents are generated solely as a result of sulphide oxidation, this is quite incorrect, as is obvious from the fact that graphite, a metallic-type conductor, will also generate currents that may be even stronger than the ones with sulphides, and without any sulphides being present.

The flow of these spontaneously generated currents down the sulphide body, out into the country rock, and then back into the sulphide body at its apex, results in a point of inflow of current, or negative centre, above the apex of the deposit. The potential difference, or voltage, of this negative centre compared to that of the distant, surrounding ground may be anything from about 0.1 volt to as much as 0.6 to 0.7 volt, and sometimes even more. It is this difference in potential that is the indicator of a buried, metallic conductor and for which the geophysicist searches by means of a systematic exploration of the ground. The apparatus employed to measure these weak potentials consists of a measuring instrument called a millivoltmeter potentiometer connected to a pair of porous (unglazed earthenware) pots, known as non-polarizing electrodes, for making electrical contact with the soil. Each pot is filled with a saturated solution of copper sulphate into which a small bar of copper projects. The copper bars are connected by wires to the terminals of the measuring instrument. One electrode is kept stationary on the ground at a base point, and measurements are taken as the other electrode, connected to the instrument by some 1,500 feet of wire, is moved out along a traverse line and placed in contact with the earth at regular intervals. The usual procedure is to take observations at intervals of 50 or 100 feet along a grid of parallel lines. The spacing between the lines of the grid is from 50 to 400 feet, depending upon the objective of the survey. Care must be taken to see that the pots are placed on fresh earth, not on decaying humus, which introduces small false potentials.

The strength of the potentials generated depends largely on the concentration of sulphides in the deposits, and not at all on the width of the deposit. The more massive the sulphides, the stronger are the potentials generated. As the percentage of sulphides within a vein structure or lens decreases, the increasing internal resistance caused by the non-conducting gangue minerals decreases the effective voltage. Interpretable reactions are usually not observed above deposits containing less than about 5 per cent sulphides. The potential generated by the deposit and that observed at the surface of the ground in a geophysical survey may not be the same. With the increasing thickness of overburden, the observer is farther and farther away from the battery which he is measuring, and the reactions at the surface may become too weak to interpret when the overburden is more than about 300 feet thick.

Another important feature is the vertical extent of the sulphide body. Pockets, short gash veins, and small lenses with limited vertical extent produce local centres of electrical activity without much breadth. On the other hand, large lenses and continuous veins extending to considerable depths produce strong, continuous bands of electrical activity which are also spread over considerable width.

Thus, the actual readings of potentials recorded at the surface, and the pattern of their distribution, furnish useful guides in evaluating the underlying, causative mineralization. This does not mean that the geophysicist can deduce the measurements of the sulphide body in feet, nor can he predict the percentage of sulphides present, much less venture any guess as to what metals are to be expected. It does mean, however, that he can obtain some indication of the type of underlying deposit and furnish a very valuable guide to a subsequent drilling program. Of all the geophysical methods applicable to the search for sulphides, the spontaneous polarization technique provides the quickest field procedure and also furnishes highly definite information as to the occurrence or absence of sulphide mineralization. The possible occurrence of graphite in the area introduces a qualification of the last statement, however, since the method also reacts to that mineral. Graphitic formations can occasionally be differentiated from sulphide bodies either because of the strength of the potentials recorded, or of their pattern of distribution. Usually such differentiation is not possible, and the results must be interpreted with the full realization that, where graphite is likely to occur, it can be responsible for the potentials observed.

With the exception of graphite there are but few insignificant factors to lead the geophysicist astray when interpreting the spontaneous polarization results. Pronounced slopes, for example, sometimes introduce a topographic effect, usually minor, which can readily be detected and should be discounted. The method can be used to trace metallic pipelines, so naturally when operating in a district where buried pipelines are likely to be found, the operator must be on the watch for them. Water moving just beneath the surface through sand or gravel beds may set up weak potentials, but these are not to be confused with the stronger ones associated with sulphide deposits. Where sulphide deposits lie beneath lake waters, the method is not usually applicable except over the ice in the winter.

In the foregoing, the emphasis has been placed on the principal application of the spontaneous polarization technique to the direct search for sulphide bodies. For this, its speed, simplicity, and definitiveness make it very useful. In addition, the method can sometimes be used to gain an idea of the structure of concealed bedrock formations, as when the sulphides themselves, or graphitic formations, have been involved in dislocations or foldings, or have selectively followed such features. Sometimes the tracing of graphitic horizons furnishes stratigraphic or structural data that assist in locating associated formations of economic interest.

In conducting spontaneous polarization surveys, the geophysicist observes certain physical reactions that arise within a mineral deposit. He cannot see the minerals, nor can he assay them, and unfortunately the physical reactions he observes do not indicate the precise minerals or metals present. The reactions merely indicate that a certain class of minerals, the sulphides, may be present. Furthermore, there is no indication of the volume of mineral involved

in the reactions. It therefore becomes necessary to correlate the geophysical indications with all available geological data, to see whether there is any geological basis for believing that minerals of one type rather than of another may be present, and whether the conditions are right for deposition of a large amount of mineralization.

Resistivity Method

When an electrical voltage is applied across a specimen of a substance, a current is caused to flow through the specimen. The ratio of the voltage required to cause a certain electric current through the specimen to that current is referred to as the 'resistivity' of the substance. This 'resistivity' is so called because it is a measure of the resistance offered by the substance to the flow of current. It is measured in units of ohm-centimetres or ohm-metres.

Most rock materials, when perfectly dry, are excellent insulators. In practically all rocks, however, the individual aggregates of minerals, or grains, are separated one from another by microscopic holes called pore spaces. The ratio of the volume of the solid mineral grains to the pore spaces within the entire rock mass is dependent upon the size and shape of the grains and the degree of compaction of the rock. The pore spaces contain appreciable amounts of water with salts in solution even above the permanent water-table, that is, the level below which water is always present in rock or overburden at that locality. It is because of these solutions that all rocks in their natural states conduct electricity to some extent. This type of conduction is called 'ionic'. Naturally the greater the porosity or fissuring of a rock the more water it can contain and the lower will be its resistivity. Different formations can often be distinguished one from the other by their difference in resistivity, which indicates a general difference in average porosity. However, because the physical condition of a rock mass will often vary from place to place within the mass, it cannot always be said that a specific narrow range of resistivities characterizes a particular rock type. A tenfold variation may often be encountered within one rock type.

Soils, swamps, lakes, and streams usually have much lower resistivities than the underlying consolidated rocks. In general, igneous rocks have higher resistivities than sedimentary rocks. The resistivity of sedimentary rocks frequently increases with the age of the rocks, since increasing age generally means increased compaction. Rocks of the Precambrian Shield are among the most highly electrically resistive in the world, with resistivities as much as 100,000,000 ohm-centimetres. At the other end of the scale salty shales of much more recent age exhibit resistivities of less than 100 ohm-centimetres.

There are a number of rock constituents that have the ability to conduct electricity, even in a perfectly dry state. These include graphite, a wide variety of metallic sulphides, and a few metallic oxides; they have the property of 'electronic' conduction. This is the manner in which metals themselves conduct. As a class, these minerals are much better conductors than barren rock and hence can be readily differentiated from the rocks by their greatly decreased resistivity.



Unknown

Plate 63. Conducting a resistivity survey.

General Field Procedure

Electric current may be caused to pass into the earth by connecting a direct-current or low-frequency alternating-current generator to two contact points, such as metal stakes driven into the ground. If the material between the two current stakes is homogeneous, the current will flow through it in a manner that is predictable by theory. As a result of this passage of current there will be voltage differences set up in the region about and between these current stakes. These voltages are predictable, once again by theory, since they are dependent on the distance between the stakes, the total current, and the resistivity of the material. From measurements of these voltage differences on the surface of the earth it is then possible to derive the resistivity of the earth in the vicinity of the stakes, knowing the other factors involved. Because, in nature, no rocks are perfectly homogeneous, the value of electrical resistivity that may be derived by such measurements will depend on the region in which the measurements are made. In view of this circumstance, it is possible to carry out the same calculations as in the case of a truly uniform medium, but we then call the resultant value the 'apparent resistivity' of the medium in the region of measurement. The apparent resistivities will be decreased in the vicinity of areas of

increased porosity, shearing, and brecciation, and also in the presence of concentrations of the electronic conductors referred to above.

The system usually employed in Canada is to use two current stakes about 7,000–15,000 feet apart, the line joining these stakes being perpendicular to the regional strike of the formations. Voltage measurements are made in the central region along survey lines also running perpendicular to the formational strike, the current stakes remaining fixed throughout the survey. In another form of survey, widely employed elsewhere, both the current stakes and the voltage measuring points are moved, with fixed relative spacing, throughout the area to be surveyed. The latter system has the advantage that its 'depth of penetration' can be controlled by varying the relative spacing of the ground points. That is, it can be made selectively sensitive to effects arising at a certain depth. It is not widely used in Canada, however, because it is usually adversely affected by the relatively conductive soil mantle that is present over most of the Shield area.

Resistivity methods are used in mineral prospecting primarily for base-metal sulphides, although they have been used in the search for high-resistivity materials as well, such as certain hematite occurrences and quartz veins. These methods are finding increasing use in engineering problems, such as determining the depth of drift at dam sites and elsewhere, and also in the search for water-bearing formations.

Interpretation

The greatest limitation to a satisfactory interpretation of the results of a resistivity survey is that the variations from the normal or background values, i.e., the so-called 'anomalies', are such that these anomalies could be caused not only by the materials sought, such as metallic sulphides, but also by non-economic bodies. A narrow, highly conducting zone, such as a vein of massive sulphides, may give rise to the same type of anomaly as a broad zone of lower conductivity, such as might be expected from a shear zone. This is an instance of the 'saturation' effect to which resistivity measurements are susceptible. This no longer applies when the width of a zone is much greater than its depth below surface, for then a measure of the true resistivity of the zone can be obtained from the surface measurements, and hence the concentrated sulphides and a shear or fracture zone containing no sulphides can be differentiated. Even under these favourable circumstances it is not always possible to distinguish between concentrated sulphides and graphite, or between disseminated sulphides and a shear or fracture zone.

Valleys in the bedrock surface covered by 50 to 100 feet of overburden can also give rise to resistivity anomalies that may be of the same magnitude as those to be expected from small sulphide bodies in the bedrock.

All too often the limitations above are ignored in practice and interpretation, with subsequent disappointment when all the resistivity anomalies in an area are drilled and do not yield sulphide mineralization. It is only when these factors are understood both by those who carry out the surveys and those for whom the surveys are performed that the resistivity methods find their proper appreciation as simple, inexpensive, and relatively rapid means for base-metal exploration.

Electromagnetic Methods

The electromagnetic method of geophysical prospecting, as its name implies, is based on the use of two fundamental physical phenomena, electricity and magnetism. An elementary principle of physics is that if a current of electricity is passed through a wire, a magnetic field of force is created in the vicinity of that wire. The two phenomena, electricity and magnetism, are inter-related. Early geophysicists took advantage of this fact to devise an apparatus for use in the search for massive sulphide mineralization.

In the earliest systems, a current of electricity was passed through the ground between two metal stakes spaced a suitable distance apart. If the magnetic field was measured at the surface of the earth it was possible to determine whether or not an excellent conductor of electricity existed beneath the ground surface. If so, it was hoped that this excellent conductor of electricity might be the sulphide mineralization that was sought. Some success was achieved with the early systems, and, with recent improvements, the electromagnetic method has found wide application in areas favourable for the occurrence of base metals.

As the method developed, it became evident that it was not necessary to pass current through the ground by means of metal stakes to cause current to flow within subsurface conductors, but that an alternating current flowing in a loop of wire suspended above the surface of the earth will cause currents to flow in buried conductive deposits. The process by which this takes place is termed 'induction'. The steps in this process are as follows:

(1) The alternating current flowing in the loop creates an alternating magnetic field (primary magnetic field) in the vicinity of the loop.
(2) The primary magnetic field will cause currents to flow in any subsurface conductor.

Induced currents flowing in a subsurface conductor will create a magnetic field (secondary magnetic field) that can be measured at the surface of the earth. This secondary field is absent unless an excellent conductor of electricity exists beneath the surface.

The indicating device used to measure the magnetic fields in the electromagnetic method consists of a 'search coil' connected to either a sensitive voltmeter or a pair of earphones. The intensity of the magnetic field cutting the 'search coil' is indicated by the reading on the voltmeter or the loudness of the signal in the earphones.

In a technique popularly employed in Canada, a coil of wire of several turns is suspended in a vertical plane from a guyed mast. A strong alternating current is passed through this coil, which, in the vicinity of the coil, creates an alternating magnetic field, called the primary field. If a highly conductive mass, such as a massive sulphide body, is near the coil, currents are induced in this mass. Induced

currents flowing in the conducting body will in turn create another alternating magnetic field known as the secondary field. If strong enough, the secondary magnetic field distorts the primary magnetic field. This distortion can be measured in terms of 'dip-angles'. An understanding of these measurements may be obtained from the following paragraphs.

The magnetic field caused by a current flowing in a long wire spreads out from the wire concentrically, as shown in section on Figure 32. At any point in the field, a search coil will have a voltage induced in it that is dependent upon the frequency of the alternating current in the transmitting coil, the number of turns of wire in the search coil, its area, and the angle it makes with the lines of force. In the accompanying diagram the search coil is shown in positions in which the voltage induced in it is a minimum. If the long wire is replaced by a large sulphide body, the same considerations apply. However, in actual practice, conditions are more complicated than this because the secondary field due to the conductor is superimposed on the primary field of the vertical coil (*see* Fig. 32).

A hypothetical traverse taken along the ground above and at right angles to such a conductor is shown on Figure 32. The directions of the primary and secondary fields are indicated by arrows whose lengths are proportional to their respective field strengths. The direction and intensity

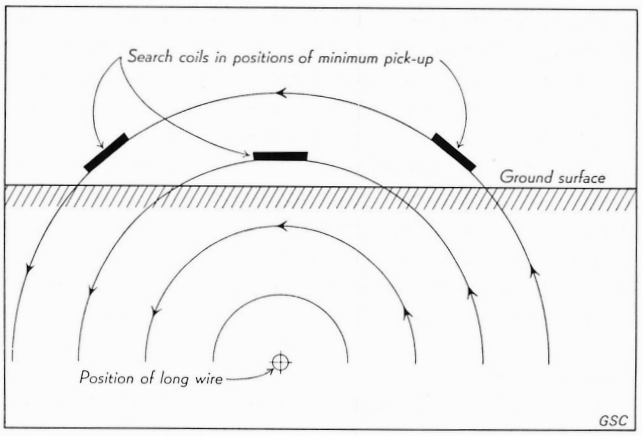

Figure 32. Theoretical illustration of the electromagnetic method.

of the resultant or 'distorted' field are found by employing the so-called 'parallelogram of forces' as shown. These resultant arrows are parallel to the plane of the search coil when it is rotated into a position where it is not cut by any of the lines of force of the resulting field. In these positions, no voltage is induced in the search coil and hence, if a pair of earphones is connected across the search coil, no signal is heard in the earphones. When the search coil is tilted in either direction away from the position of minimum voltage, a signal is heard in the earphones.



Plate 64. Conducting an electromagnetic survey (courtesy Lockwood Survey Corporation Limited).

The angle between the resultant arrow and the horizontal at any point is termed the dip-angle, and its determination is the fundamental measurement in the search for conductors. A typical dip-angle curve is given on Figure 33 in which dip-angles are plotted along a traverse across a massive sulphide orebody. Over barren ground, the dip-angles are almost zero. The approach to a conductor is marked by increasing dip-angles which in turn decrease to zero directly above the conductor, and then increase, but in the opposite sense, beyond the conductor. Finally, far from the conductor, they reduce to zero again.

Field Procedure

To overcome complications caused by dip-angles arising from elevations and topographical effects, the plane of the transmitting coil is oriented for each observation so as to pass through the point of observation. If the relative locations of the transmitter coil and the search coil are known to within a few feet, the transmitter coil can be oriented so as to make errors negligible, even in the most rugged terrain. Hence, the dip-angle profiles are directly interpretable and require no topographic or other correction. When the coils are properly oriented the occurrence of a dip-angle indicates a conductor.

In operation, the transmitting coil is erected at a convenient location and traverses are made at right angles to the assumed formational or structural strike on each side of the location of the transmitter. The traverses are usually made along lines 400 feet apart, during a reconnaissance survey, and closer together when detailed surveying is required. The distance traversed along any one line from the corresponding transmitting-coil location is seldom greater than 2,000 feet. Thus it is necessary to employ several transmitting-coil locations in order to complete the survey of a mining property.

Advantages and Limitations

The electromagnetic method described above is used chiefly in the exploration for such excellent electrical conductors as massive metallic sulphide deposits or for massive magnetite. It can, however, be used advantageously in the search for moderately conductive materials if the frequency of the alternating current employed in the transmitting coil is chosen appropriately. As a general rule, the lower the electrical conductivity of the deposit sought, the higher must be the operating frequency of the electromagnetic unit. There is however, a specific upper limit to the useful frequencies, above which overburden and poorly-conducting shear zones, faults, etc. give rise to obscuring anomalies. Most electromagnetic surveying is performed at a frequency of 1,000 cycles per second. The most suitable frequency for the survey of any one area should be determined before large-scale application of the method is made.

Very little, if any, response is caused by swamps and other topographic features when the survey is performed at a frequency of 1,000 cycles per second. In fact, the ability to operate satisfactorily under almost any topographic conditions is one of the major advantages of the electromagnetic method over other electrical methods.

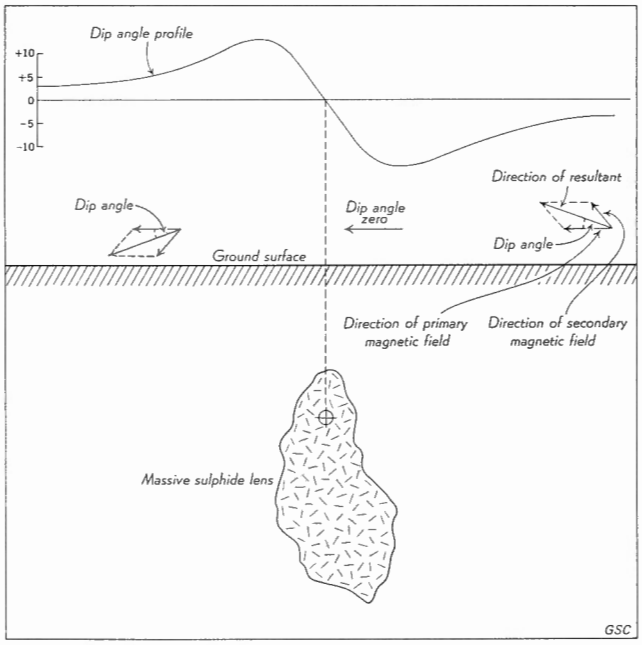

Figure 33. An idealized traverse across a massive sulphide lens.

Graphitic shear zones and sedimentary horizons are frequently the cause of electromagnetic anomalies (as is the case with other electrical methods). The method using 1,000 cycles per second does not indicate contacts between two rock types unless one or other is an excellent conductor or unless an excellent conductor lies along the contact. Thus this method does not indicate structure in the manner of a resistivity method, unless such excellent conductors as sulphides, magnetite, or graphite follow structural trends. The method using 1,000 cycles per second occasionally detects faults.

The interpretation of data from electromagnetic surveys is usually based on accumulated experience and on comparison with results of scale-model experiments. The scale-model experiments are performed in the laboratory under controlled conditions and permit the geophysicist to determine the general nature of the anomalies to be expected from many typical bodies. It is often possible to estimate the size, shape, and depth of a conductor from the results of an electromagnetic survey by comparison with scale-model data. These factors then have to be assessed in light of the available geological data.

The electromagnetic method is ideally suited for the detection of massive sulphide and magnetic deposits. It can be applied satisfactorily under almost any topographic conditions. The correct operating frequency for the electromagnetic method should be determined before extensive application of the method is made in any one area. The possibility of success of the method and the determination of correct frequency often can be estimated by a study of both the general geological conditions and the types of rock and ore in the district. As will be seen from the above discussion, the application and interpretation of the method require experience.

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Induced Polarization Methods

Induced polarization surveys have become popular during the last few years, after several orebodies were found with their assistance. The methods are developments of a system used previously. They are made on the ground only, and are particularly suitable for some kinds of disseminated deposits. The method was attempted in the 1920's, when it was called 'provoked polarization'. It was revived about 1948 when it was found that electromagnetic surveys gave poor results with disseminated copper deposits in United States.

The basis of induced polarization methods is that when an electrical current, passing through certain kinds of ground between electrodes placed at the surface, is interrupted, the electrical potential is reduced (decays) gradually and measurably. This condition is related to electrochemical reactions in groundwater containing dissolved electrolytes and surrounding disseminated grains of certain minerals. The current causes overvoltage which decays with time. The effect is caused partly by ions passing through the interstitial water and partly because some sulphide minerals and graphite permit passage of current. The method has been most effective where grains of metalliferous minerals are disconnected, with large surface areas and large ionic effects, and where the host rock has suitable resistivity. Current is introduced by metal stakes and potential is measured across non-polarizing electrodes placed in porous pots, using arrays similar to those of resistivity surveys. In some techniques frequencies are measured and in others, such as the Eltran, the distortions of pulse over a short time are measured.

'Metal factors' for different minerals and rocks are compiled from laboratory tests. Some such determinations are:

normal granite	1–5
normal mafic rocks	5–50
finely disseminated sulphides	50–100
normal disseminated sulphides	100–20,000
fractures filled with sulphides	1,000–10,000

Graphite, sericite, serpentine, and chlorite react in the same manner as sulphide minerals, which gives rise to problems in the use of induced potential methods. False anomalies are reported to have been experienced in regions containing permafrost.

One case-history indicates that the first survey over what proved to be a large low-grade deposit yielded results only slightly above background, and that a later survey using a different frequency and spacing indicated a significant anomaly. Another case-history showed that the continuity of conduction was destroyed by certain positions of rounded (colloform) grains.

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13 geochemical prospecting

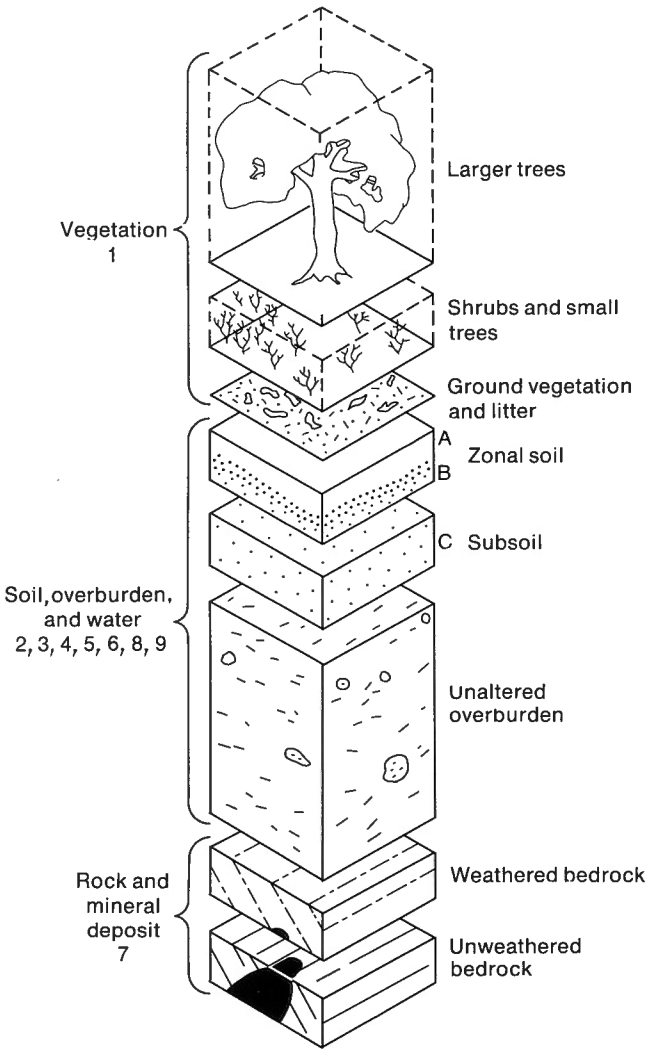
INTRODUCTION

Very small amounts (traces) of one or more of the elements present in a mineral deposit are also commonly dispersed in the vicinity of the deposit; this is the basis for geochemical methods of prospecting. This dispersion may be in the host-rock of the deposit, in soil, or other overburden, in stream sediment, in water, or in vegetation. Geochemical prospecting is an application of general geochemistry, which deals in a more academic way with the relations of chemistry to geological problems, more particularly with the way in which the principal and minor constituents of rocks and mineral deposits are associated with one another. General geochemistry is called 'pure' or 'classical' geochemistry by some writers, who consider geochemical prospecting to be part of 'applied geochemistry'.

Pure geochemistry became an organized part of geology and chemistry late in the last century, and has advanced greatly in this one. Its task as defined by Goldschmidt, one of the pioneers, includes the determination of the relative and absolute abundances of the elements in the earth, and the study of the distribution and migration of the individual elements in the various spheres of the earth. These spheres include rocks (lithosphere), water in surface bodies and in rocks (hydrosphere), gases (atmosphere), and life (biosphere).

Modern geochemical prospecting was first established in the Scandinavian countries and in Russia fairly early in the present century. It was foreshadowed long ago by panning for heavy minerals and by observations on the taste, smell, or colour of water issuing from the vicinities of mineral deposits, and on the presence of certain plants near deposits. Trained dogs have been used in Scandinavia to scent the sulphur in fragments of sulphide minerals in glacial drift, and reconnaissance geochemical surveys in Ireland during the last few years were said to be based on reports that domestic fowl commonly died in certain areas, apparently from eating soil containing lead.

About 1945 the decline in the opportunities for conventional prospecting of outcrops in the United States and Canada directed attention to the possibilities of geochemical prospecting. It had not previously been tried in Canada,



GEOCHEMICAL PROSPECTING METHODS

1. Plant geochemistry
2. Soil geochemistry
3. Bog geochemistry
4. Water geochemistry
5. Stream sediment geochemistry
6. Overburden geochemistry
7. Rock geochemistry
8. Studies of pathfinder (indicator) minerals - in any environment
9. Boulder tracing, etc.

GSC

Figure 34. Diagram illustrating the various environments studied in geochemical prospecting (modified after J. A. C. Fortescue).

except for a survey in Newfoundland about 1940, because of the success of other methods and because of a general opinion that the intense glaciation of most parts of Canada had rendered all but rock-sampling methods unsuitable here. Research has shown, however, that although glaciation has caused complications, these do not apply for some areas or can be overcome. As discussed more fully on page 120, a recent study showed that of fifty-six mines brought to production in Canada in the period 1956–66, and discovered since 1945, eight were found as a result of combined approaches including geochemical prospecting in six. Also, a few important prospects have been found recently by combined methods of which geochemical prospecting

was the principal one, and for other important prospects geochemical prospecting was a supplementary aid. No significant Canadian discovery is yet known to the writer to have resulted entirely from geochemical prospecting. Research was begun in the Cordilleran region by Warren and his associates in 1945, mainly on the possibilities of vegetation. Research on various methods in several parts of Canada was soon undertaken by Riddell and by Boyle and his associates of the Geological Survey of Canada. Others have contributed recently, notably Sutherland Brown who has made a substantial contribution to the study of soils near known deposits in British Columbia. Extensive geochemical prospecting was undertaken by Kennco Explorations (Canada), Limited in various parts of the country, by New Jersey Zinc Limited in New Brunswick, and by Atlas Explorations Limited and associated companies in the Yukon; many other companies have made surveys, apparently on smaller scales.

Geochemical prospecting is concerned with attempts to reveal dispersions of elements, mainly metals, sufficiently above average amounts to be classed as anomalies. Geochemical anomalies generally have the advantage of occurring over a larger area than the deposit itself, thus enlarging the target for subsequent prospecting. The strength of an anomaly bears little relation to the richness of the deposit with which it is associated, because several other factors are involved. Geochemical prospecting requires systematic sampling, the analysis of large numbers of samples by fairly rapid and cheap, but reliable, methods, and the results require interpretation by experienced persons. The methods of analysis generally do not need to be as precise as the assays on which the actual testing and mining of a deposit are based, because geochemical analyses are used only to indicate or to narrow a target, but they must be suitable for estimating very small quantities.

Most geochemical analyses are performed in permanent or portable laboratories, by technicians who are supervised by one or more chemists or geochemists. Kits of various kinds that can be carried in the field are available and have been adequate for certain kinds of systematic surveys in which the tests are made either at the sampling site or in camp. They are not intended for random tests such as are sometimes made effectively with a radioactivity detector or mineral lamp when searching for uranium or tungsten. The only instances known to the writer in which geochemical kits have been used effectively were where they were used by, or under the supervision of, geochemists, geologists, or engineers. Long and short courses in the use of kits by persons without university training are now offered. They have not been available long enough to provide full evaluation of their potential. Authorities consulted by the writer agreed that, after such training, persons with suitable aptitudes and schooling would probably be able to make satisfactory surveys of certain kinds, but that they would be most likely to be effective if the exact methods were chosen and the results interpreted by company or consulting geochemists. The authorities also agreed that although it would not be impossible for a person to learn the use of kits entirely on his own, he would be doing it the hard way.

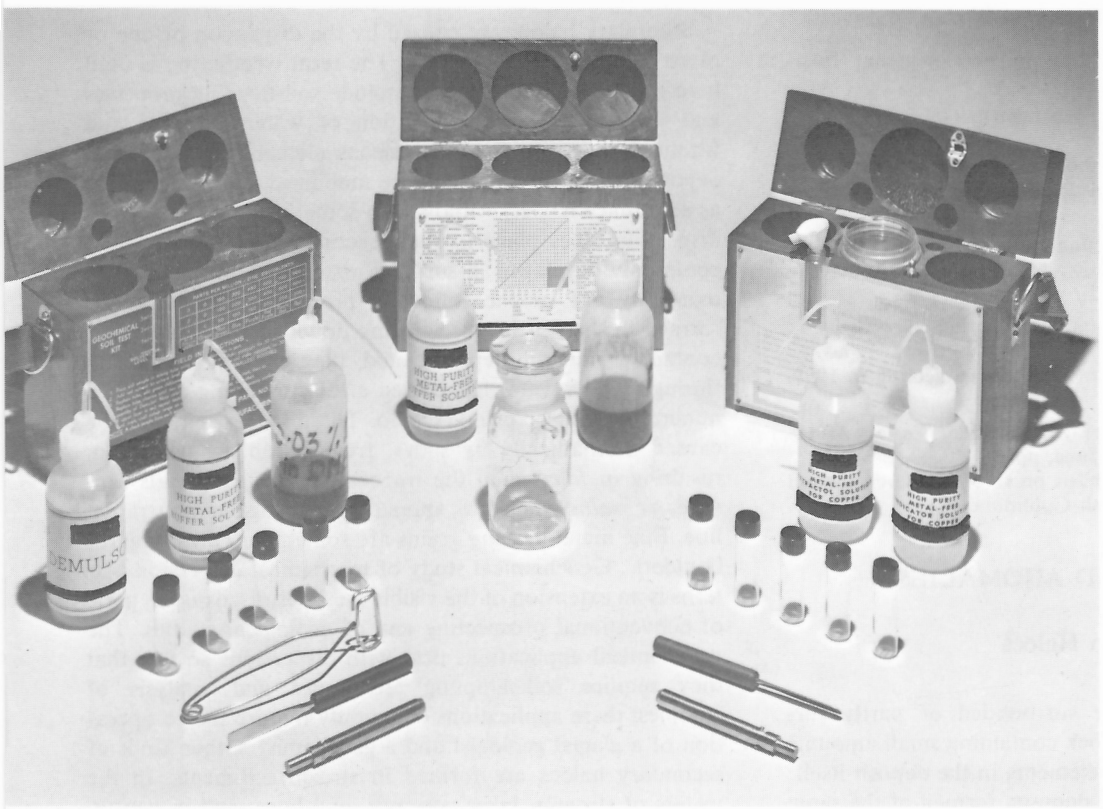


Plate 65
Small geochemical field kits (courtesy Clive Peacock Photography Limited).

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DISPERSION AND ANOMALIES

Dispersion Haloes

Primary Haloes

Many mineral deposits are surrounded or partly surrounded by a zone or *halo* of rock containing small amounts (traces) of some or all of the elements in the deposit itself. This is generally true both for deposits formed at the same time as their enclosing rocks (syngenetic deposits) and for deposits introduced into the rocks later (epigenetic deposits). Zones of these kinds are called *primary haloes* because they originated at about the same time as did the deposit itself, and because they are in the same environment, namely rock. A primary halo may surround a deposit fairly uniformly, or it may lie along a stratum, fracture, fault, or other structure that was particularly favourable for migration of fluid associated with the emplacement of an epigenetic deposit. Primary haloes that followed a favourable upward path are sometimes called *leakage haloes.*

Zones of wall-rock alteration surrounding mineral deposits were discussed in Chapter 11. No sharp distinction can be made between wall-rock alteration and primary dispersion haloes. In general, however, zones of alteration are noticeable by eye or contain features that can be determined by using a microscope or by analyzing the main components of the altered rock. The typical features of a primary halo would probably be invisible, even microscopically, and would be detectable only by analysis of elements present in trace amounts. Although no statistics are available, dispersion haloes are generally wider than most alteration haloes. The size of a halo may bear little relationship to the size or richness of a deposit, because dispersion depends largely on the mobility of an element, or on the way it is bound chemically in the deposit, or on the permeability of rocks or structures.

Some geochemists, particularly in the USSR, consider that the term 'primary dispersion halo' is not always descriptive and prefer such expressions as 'zone of distribution' and 'zone of metalliferous mineralization'.

Secondary Haloes

Secondary haloes are caused by the dispersion of one or more elements by weathering. The term weathering is used here in its broadest sense, to include soil-forming processes and the underground circulation of water in pores and fractures in rocks. By these means elements in a mineral deposit or in a primary halo are mobilized and re-deposited as secondary haloes. Although in some instances secondary dispersion takes place in rock, secondary haloes are more commonly developed in surficial material or other environments by one of the following processes. They may be formed in the soil by the wearing down of rocks and their contained mineral deposits, and they may form in soil through which water has passed after circulating through a mineral deposit or primary halo. These haloes may also be caused mechanically by slides, frost action, or glaciation, resulting in *fans* when the traceable material spreads fanwise, or *trains* when it is spread in an irregular or straight line. Fine metal-bearing grains are sometimes called 'microboulders'. Geochemical study of mechanical dispersion patterns is an extension of the visible methods discussed as parts of conventional prospecting and of geological studies. The geochemical applications deal with dispersions so fine that they require soil-sampling techniques and analysis of samples; these applications commonly require the co-operation of a glacial geologist and a geochemist. Other kinds of secondary haloes are formed in stream sediments, in the waters of streams, lakes, swamps, and bogs, and in vegeta-

tion. Also, the possibility that traces of some mineral deposits may be detectable in the air above them is being studied. The ease by which an element is dispersed (its *mobility*) depends on many factors: the way it is bound chemically with other elements; the presence of still other elements that might speed or retard mobility; solubility of its salts; acidity of rock, water, or soil; ease of oxidation; presence of organic matter; and climate. Many of the metals most sought in prospecting are fairly mobile under suitable conditions; these include zinc, lead, silver, copper, uranium, molybdenum, nickel, and chromium.

Regardless of whether they are in rock or other material, dispersion patterns or haloes are sometimes referred to as 'syngenetic' if they were formed at the same time as the host material, and as 'epigenetic' if the metal was introduced later from a different source.

Anomalies

Most of the elements are present in very small amounts in rocks, soils, waters, and plants. The amounts normally present are called *background* amounts. The background for different elements varies greatly, and it commonly varies to some extent from place to place in the same kind of rock, soil, etc. The average amount of an element present in typical igneous rocks is called the 'clarke' of that element; the average amounts of elements in other kinds of rocks, and in soils, are roughly comparable to the clarkes. All abundance figures are revised periodically as more data accumulate. For most geochemical surveys average background figures cannot be obtained satisfactorily from the literature, but must be determined for the particular area and project. The upper limit of the normal background determined for an area is called the *threshold*, and amounts two or more times greater than the threshold are called *anomalies*. An anomaly indicated by analyses to average about twice the background is commonly called a 'first-order anomaly', and so on. In places, non-significant anomalies may be present as a result of slight but widespread increases in the amount of a metal present in rock or soil, or as a result of contamination or other causes.

Dispersion patterns and anomalies may be regional or local. Regional ones are determined from information in maps or reports or by reconnaissance geochemical surveys, and may indicate areas for more detailed prospecting by geochemical or other methods. Large parts of the earth's crust in which one or more elements occur in more than average amounts have been called 'geochemical provinces'. In such regions the element or elements concerned may be distributed fairly evenly, or in many individual anomalies. Geochemical 'provinces' are related to metallogenic provinces (*see* Chapter 11) but the distinctions have not yet been clearly defined. To avoid confusion, the expression 'regional geochemical pattern' is used tentatively in this publication.

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NOTE: Examples of anomalies, illustrated by plans and diagrams, are contained in the book by Hawkes and Webb listed previously, and in other publications listed in this chapter. Examples of geochemical maps accompany *Geol. Surv. Can.* Bulls. 32 and 118.

ROCK-SAMPLING SURVEYS

Primary dispersion haloes or patterns in bedrock provide important objectives for geochemical prospecting because they may be related more directly to mineral deposits than patterns in other materials, and for additional reasons. Although they also present disadvantages that so far have made them less attractive than other approaches, such as haloes in soils, surveys of rocks in place are described first because of their more fundamental nature.

The main advantages of geochemical investigations of bedrock are: (1) patterns may be related directly to mineral deposits; (2) the samples can be taken during geological surveying, systematic prospecting programs, and diamond drilling, and previously stored specimens and cores can be tested; (3) bedrock is not so liable to contamination by mining wastes as are soil, water, and vegetation; and (4) the data may contribute to the understanding of the origin of mineral deposits. Disadvantages are: (1) investigations of this kind are confined to bedrock whereas the main hope of geochemical prospecting at present is to provide means of detecting deposits covered by overburden in areas where outcrops are scarce or lacking (bedrock studies do, however, offer possibilities for the detection of 'blind' deposits covered by barren or weakly-mineralized rock): (2) samples must usually be crushed, ground, and analyzed in a laboratory (exceptions are mentioned in connection with mercury detectors used in 'indicator' surveys, and with instruments for analyzing rock in place); (3) anomalies may be caused by the presence of a metal in quantities slightly above background but quite unrelated to deposits of economic interest; and (4) weathering or leaching of rocks or mineral deposits may cause conditions that may have to be considered when interpreting rock surveys, but these effects appear to be less significant in Canada than in some other countries.

Chip sampling of outcrops is generally suitable for preliminary surveys, but channel samples are sometimes taken in detailed investigations. In routine sampling of drill-cores 1-foot intervals are recommended. Chip or core samples are sometimes grouped as composites. Unweathered rock should be sampled if possible.

Canadian Experience

A soil, stream-sediment, and rock survey in New Brunswick, involving tests for several metals, resulted in a discovery of tin that is being investigated thoroughly. A geochemical study of the Cobalt silver camp included analyses of drill-cores and chip-samples taken outwards from known veins in outcrops and underground workings,

and indicated patterns that encourage further work of this kind. About 8,000 samples taken during a geological survey of a large area in northwestern Ontario were tested for copper but tests for other metals and full evaluation even of the data on copper have not been completed. The results obtained show a general increase in copper in the more mafic rocks but no outstanding anomalies; the survey also provided experience and conclusions useful for further projects of this kind. Experimental surveys of the mercury content of rocks of certain mining camps have been undertaken in British Columbia as explained later in the section on pathfinder elements.

Both classical and prospecting geochemical studies have provided much data on the average contents of various metals in igneous, sedimentary, and metamorphic rocks and on the chemical ways in which the metals occur in them. Much more research and experience of these kinds are needed to provide adequate information on background levels of metal contents for various rocks, structural conditions, and other factors, and on methods of sampling and testing. For example, the survey in northwestern Ontario mentioned above confirmed the opinion of earlier workers that copper occurs mainly as minute grains of chalcopyrite, whereas zinc appears to occur mainly in ferromagnesian minerals such as biotite; these findings indicate that the whole rock should be analyzed for copper but that it might be best to separate the ferromagnesian minerals before analyzing for zinc. As lead appears to be carried mainly in the feldspar grains of rocks, it might be best to prepare concentrates of feldspars for testing for lead.

In various surveys, sampling has been done by channelling, combining chip samples as 'composites', taking representative specimens, and crushing and panning on the spot. Only one type of rock should be included in a single sample. Notes of geological conditions should be kept for each sample. A type of gamma-ray spectrometer (*see* Chapter 12) recently available permits measurement of the uranium or thorium content of rock in place; its possibilities are being investigated, as are the possibilities of developing such instruments for other metals. An instrument that indicates beryllium content is mentioned in Chapter 15 in the section on "Beryllium."

The following advice on geochemical studies of rock samples and drill cores is contained in a recent summary by Boyle (1967):

> In addition to analyzing the rock and core samples of the massive rocks, all shear zones, fractures, contorted zones, and altered zones should, likewise, be sampled and analyzed for their metal content or for indicator elements such as mercury, arsenic, and antimony. A detailed map showing all of these geological features, as well as any small veins, no matter what size, should be plotted and the metal or indicator element contents of the samples entered at the appropriate sites. When drilling is done, sections with all of this detail should also be prepared. Only in this way is it possible to observe patterns in the primary metal or indicator element dispersion in the rocks, and from these patterns to predict the locus of large deposits. It should be constantly borne in mind that most large deposits have a halo of smaller satellites developed in subsidiary or parallel fractures, faults, folds, and other structures. Trace element work on small shear zones, fractures, and faults increases our ability to differentiate smaller and smaller satellites. It may well be that the data, when plotted and contoured, will show an increase in the metal or indicator element content in a certain direction, or that the number of metal-bearing fractures, crenulations, and other discontinuities in the rocks increases toward some favourable geologic structure or zone containing the sought-after deposit.

Suggestions for Additional Reading

Emslie, R.F., and Holman, R.H.C.
1966: The copper content of Canadian Shield rocks, Red Lake – Lansdowne House area, northwestern Ontario; *Geol. Surv. Can.*, Bull. 130.
Maps 50-1963 to 56-1963 related to this project were published separately.

Warren, H.V., and Delavault, R.E.
1960: Aqua regia extractable copper and zinc in plutonic rocks in relation to ore deposits; *Trans. Inst. Mining Met.*, vol. 69, pp. 495–504.

SOIL-SAMPLING SURVEYS

The sampling of soil and overburden is an important branch of geochemical prospecting because soils may contain anomalous amounts of metals useful for outlining regional patterns of distribution and for localized prospecting. The term 'soil-sampling' is used because it is short. It is used here to include all forms of overburden, which are of two main kinds: residual and transported. Residual soils are formed by weathering of rock without transport of the weathered material, and transported soils have been moved by streams, glaciers, slides, or winds. Agricultural soil scientists restrict the term residual soils to layers of overburden that have been changed by weathering, leaching, the accumulation of leaves or other organic matter, or by bacterial action. Both the general and the soil-science usages are employed in geochemical work and literature.

In soil-science terminology, soils are usually divided into three layers called *horizons*, a few inches to a few feet thick, which may or may not all be present at a particular locality because the soil-forming process may not have been completed or because one or more horizons may have been removed by subsequent erosion. The sequence at a particular locality is called the *soil-profile*. The lowest horizon, called C, is the parent overburden from which the higher horizons are formed. In residual soils the C zone represents the underlying bedrock but in transported soils it may or may not do so. The C horizon consists of grains of rock that may have undergone some additional weathering; it contains a minimum of organic matter. The C horizon may rest directly on bedrock or one or more deeper layers of overburden may lie between it and bedrock. For example, in Canada the C horizon is commonly developed on glacial till, which might extend to bedrock or might be underlain by sand or gravel deposited by streams; in places a C horizon or a layer of till may rest on residual soil of Tertiary age. The B horizon is composed of C-type material that has been much modified by weathering, commonly with the accumulation of clay minerals, iron, and organic material some of which was derived by leaching of the A horizon. The A

zone, being uppermost, contains much material produced by the action of plants and micro-organisms, as well as decomposed plants and leaves. In general, the C zone is preferable to the B for geochemical sampling if it is available or can be reached; sampling of the A zone is not generally recommended, but exceptions are mentioned later. Soil maps available for many areas are useful in soil prospecting. On them, and in some literature, the three main horizons are commonly subdivided, the main designations now used in Canada being as follows: Ah for A-type material containing humus; Ae for material that has undergone much chemical or physical weathering; Fe for material containing much iron; $_m$ for material altered by hydrolysis, oxidation, or solution; $_t$ for clay; and C-type soil that is evidently unrelated to the underlying rock is called IIC. Different designations were used in some early Canadian literature and are still used in some countries. For example, Ah was formerly called A1, and Ae was called A2.

Soils contain traces of metals for various reasons. Soil grains, angular fragments of rock, pebbles, or boulders commonly contain metalliferous rock-forming minerals or residuals of minerals from deposits. Also, groundwater circulating in the soil may have dissolved metals from bedrock or from other soils and redeposited them in the soil horizons owing to changed chemical or physical conditions. Residual soils are generally fairly representative of conditions in the underlying bedrock, whereas transported soils may contain metals from a fairly close or a distant source. Glacial soils may contain metals derived from residual soils that were reworked and transported by glacial action, or they may contain fragments plucked from bedrock or mineral deposits over which a glacier travelled. In general, residual soils offer the best possibilities for geochemical prospecting and soils that have not been transported far are more favourable than most glacial soils. Glacial soils may be too mixed and far removed to be useful, or they may yield meaningful anomalies in the light of the glacial history of the area in question.

Canadian Surveys

Canada is underlain mainly by glacial soils and contains the largest individual tract of glacial soils in the world. Most Canadian soils are 'podzols', a term used by soil scientists to describe the soils typical of well-drained, humid, temperate regions. North of the Canadian podzols or higher on mountain slopes, are 'tundra' soils and muskegs characterized by cold climate, poor drainage, and, commonly, by permafrost. Residual soil is present in the unglaciated part of the Yukon. Some is probably present in patches underneath glacial deposits, particularly in those parts of the Cordilleran region where topographical features prevented removal as complete as took place in most other parts of the country, but little information is so far available on their possible presence.

Experimental surveys near known mineral deposits, as well as surveys for actual prospecting, have been attempted mainly in the Cordilleran and Appalachian regions where glaciation was, on the whole, less sweeping than over the Canadian Shield. Some experiments yielded encouraging results and the discoveries of some important deposits were attributed partly to soil surveys. Experimental surveys in parts of the Canadian Shield have indicated that certain conditions may be suitable for soil surveys there. Some of the published results of these investigations are summarized below.

Cordilleran Region

Most soil in British Columbia is podzolic but areas in the southern interior of the province contain semi-desert soil, and parts of the higher mountains are covered by tundra and muskeg. In the main parts of the mountainous areas soil development is largely 'juvenile', normal soil-forming processes having been retarded by glaciation and later by cool or arid conditions. Sutherland Brown reported that in much of British Columbia a dark humus layer (Ah or Al), a grey leached zone (Ae or Az), and a rusty enriched B zone may have a total thickness of only a few inches or feet, and that the unmodified parent overburden is commonly within a foot of the surface except beneath bogs. One soil-sampling survey made in conjunction with a magnetometer survey in British Columbia is reported to have provided encouragement in the discovery of an important copper deposit, and soil surveys using the mercury-indicator technique have shown responses over known deposits (*see* section on pathfinder elements). Warren (1966, p. 40) stated that soil-sampling surveys have been useful in many areas in British Columbia, but that in some areas the selection of the appropriate soil horizon for sampling, and the selection of a suitable chemical method of extracting the desired element from the sample, can result in success or failure.

Yukon Territory contains residual and glacial soils, much of which are permanently frozen or poorly drained in summer. Aho reported that in some places soil sampling is limited to permafrost, to thick organic cover, or to areas of deep overburden where geochemical prospecting is of little value. In places, geochemical patterns require interpretation with regard to the downslope creeping of soils as a result of frost action.

In experimental studies near known silver–lead deposits at Mayo, Boyle found that lead was enriched in residual soils near deposits and was thus a good indicator. Soils formed on till and gravel were generally unfavourable, because they are too thick and do not reflect the presence of any mineral deposits below. However, deep drilling showed that these materials can be useful (*see* ref. for 1965 on p. 174).

Appalachian Region

Soil-sampling methods have been successful in New Brunswick. Hawkes states that although the entire Bathurst district has been glaciated much of it retains a fairly deep layer of residual soil and weathered bedrock which is essentially in place, and that freely drained soils show well-developed podzol profiles. Stream-sediment reconnaissance surveys were followed by soil-sampling, geophysical surveys, and geological studies that resulted in the discovery of an important base-metal deposit. Riddell reported that farther south in New Brunswick soil surveys from the B horizon

outlined large, complex dispersion patterns of copper, lead, and zinc, and that re-analysis of the samples showed high contents of tin and molybdenum. Tin was distributed irregularly because the pattern was modified by glaciation; the molybdenum pattern was more restricted and coherent. Stripping and diamond drilling revealed deposits containing several metals that are being tested by underground workings, mainly because of their tin.

Tilsley and Rowntree made a detailed study near a small sulphide deposit in Cape Breton and reported a limited dispersion pattern for copper, lead, and zinc associated with a micro-boulder train in the C horizon. They found that samples from the Ah horizon appeared accurately to reflect the C pattern and suggested that sampling the Ah zone might be sufficient for reconnaissance.

Kelly and Assad found that some soil samples taken near molybdenum-bearing veins in Frontenac county in southern Quebec contained molybdenum. Closely spaced sampling was required. Samples containing much humus, taken from swampy areas, were enriched in molybdenum.

Canadian Shield

Detailed studies of moraines, fans, and eskers in the glacial drift covering the Shield have been made in several places. Some of these studies, which are discussed more fully in Chapter 11 as examples of advanced geological studies, have included analyses of soil samples as well as panning and visual observations. Much of the Shield in Ontario, Quebec, and elsewhere is covered by extensive sheets of clay deposited in glacial lakes. Indications to date are that soils developed on them are not suitable for geochemical surveys, but that further research is warranted on the possibility of drilling through the clays to older till or other soil that may underlie them. Useful results may be obtained from tills and particularly from the lower tills if two are present. Sampling the B or C horizon is generally recommended, but experiments by Boyle at Cobalt showed that the A zone developed on generally clayey overburden yielded best results because it was enriched by metals from the remains of leaves of trees that had apparently tapped deeper soil. In the Chibougamau region of Quebec the margins of bogs in the A zone were found to contain more metals than did other soils.

Sampling

Soil samples are obtained in various ways. The simpler are by digging pits, trenches, or cuts in banks with a grub-hoe, shovel, or trenching tool. Hand augers, some of which have a device for retaining a sample, are also used, as are post-hole diggers and crow-bars. Deeper holes are put down by churn-drills or rotary overburden-drills; such holes are commonly drilled well into bedrock, and perhaps through permafrost. Holes have been drilled in the Yukon to depths of at least 150 feet; much deeper ones have been drilled there but the amount actually in overburden was not stated. Holes were drilled on grids 100 to 400 feet apart. Samples are reported to have weighed a quarter pound to 15 pounds and in at least one project were retained separately for each 5 feet. Samples for mercury-indicator tests in one project in British Columbia weighed 2 to 8 ounces.

Pace-and-compass surveys are commonly used for locating the sampling sites of preliminary surveys. More precise methods are used for more detailed surveys.

Suggestions for Additional Reading

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1966: Exploration in Yukon with special reference to the Anvil-Vangorda district; *Western Miner*, vol. 39, no. 4, pp. 127–148.
1966: Exploration methods in Yukon with special reference to Anvil district; *Can. Mining J.*, vol. 87, no. 7, pp. 50–58.

This and the preceding paper provide valuable information on geochemical experience in the Yukon, particularly soil surveys and overburden drilling.

Boyle, R.W.
1966: Geochemical prospecting research in 1966, Cobalt area, Ontario; *Geol. Surv. Can.*, Paper 66-46.

Brief description of trial surveys near known silver veins, including studies of soil, till, glacial clay, glacial sand, rock, and material deposited by springs.

Leggett, R.F. (*Editor*)
1961: Soils in Canada; *Roy. Soc. Can.*, Special Publ. No. 3.

Overburden drilling at United Keno Hill Mines Ltd.; *Can. Mining*
1965 *J.*, vol. 86, no. 5, pp. 72–76.

Provides supplementary data on soil sampling in the Yukon.

STREAM-SEDIMENT SAMPLING

Much of the metal in a dispersion halo in rock or soil eventually enters streams and lakes, and may even reach an ocean. On the way to the oceans secondary haloes or trains are left, sometimes temporarily, in stream-sediments (silts) or in the water itself. Stream-sediment surveys have, on the whole, proved more useful than surveys of water. Stream-sediments may contain anomalous amounts of metals in grains of heavy minerals derived from the erosion of a nearby mineral deposit, or in metallic compounds precipitated chemically in the sediments after being dissolved from a mineral deposit or from grains in soil. The sediments in an entire drainage area may be sampled by including spring-deposits and samples dug or drilled from sediments through which water is seeping, but up to now in Canada most attention has been devoted to sampling silt and other sediments that have settled to the bottom of streams and ponds. This method has proved useful in several parts of the country but it cannot be expected to be applicable everywhere because some drainage areas do not contain anomalies, and others may contain anomalies resulting from leaching of soils derived from a parent mineral deposit that cannot be traced. The advantages of the method are that sediments may provide samples that are more representative than those of the water itself because they accumulated for a fairly long time; that samples may be more easily taken from sediments than from soils; and that such samples may be easier to treat and test than some other kinds. Disadvantages are that an anomaly may 'decay' over a period of time because some or all of the metal content is carried away

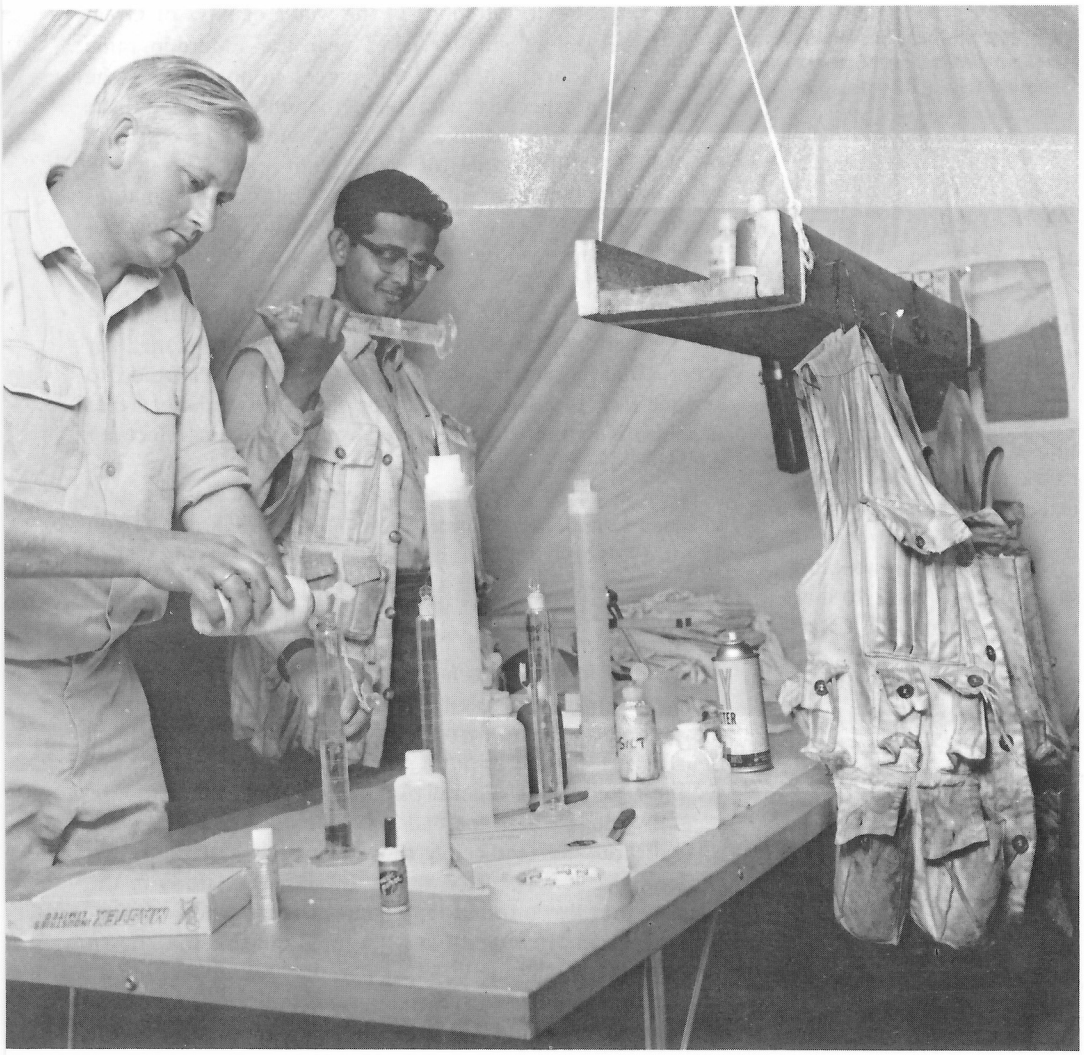

Plate 66
Tent laboratory for geochemical survey (courtesy National Film Board).

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by solution or by the transport of sedimentary grains; and that, except in remote places, sediments may be contaminated by leaching from dumps, mine tailings, and deposits from smelters and other fumes.

Stream-sediment samples may be taken by scraping the bottom or boulders of a stream, or by using a special scoop with a fine sieve attached. Wading is commonly necessary.

Canadian Surveys

Stream-sediment surveys have been made in the Bathurst district of New Brunswick, in the Stikine River region of British Columbia, and in Yukon Territory. In some of these projects samples have been taken at intervals of a quarter and a half mile and at stream junctions. These surveys have helped to outline regional patterns for copper, lead, and zinc, and experiments have shown that they should also be useful for at least silver, arsenic, antimony, and manganese. They have also been used to confirm geophysical anomalies and favourable geological features. The most common testing procedures appear to have been to make some tests, such as for acidity, and total heavy metals, on the spot and to take samples to a camp or headquarters laboratory for more detailed analytical work.

Stream-sediment sampling in conjunction with geological mapping has been tried in Canada, samples being taken only where traverse lines crossed streams; some anomalies were obtained but they could not be interpreted as fully as might have been possible if samples had been taken along the streams. Relationships between sediment and water anomalies in Yukon Territory are discussed in the section on water sampling.

Surveys of sediments in lake bottoms have been undertaken in much the same way as for stream sediments, except that samples are taken along straight lines or grids, and that sediments beneath the upper organic layers should be sampled.

Suggestions for Additional Reading

Barr, D.A.
1966: The Galore Creek copper deposits; *Trans. Can. Inst. Mining Met.*, vol. LXIX, pp. 251–263.

Contains a short description of a stream-sediment survey combined with geochemical surveys, which resulted in important discoveries. Includes comparative plans.

Boyle, R.W., *et al.*
1966: Geochemistry of Pb, Zn, Cu, As, Sb, Mo, Sn, W, Ag, Ni, Co, Cr, Ba, and Mn in the water and stream sediments of the Bathurst-Jacquet River district, New Brunswick; *Geol. Surv. Can.*, Paper 65-42.
Description of an experimental reconnaissance, illustrated by thirteen geochemical maps.

WATER-SAMPLING SURVEYS

Geochemical investigations of naturally occurring waters are commonly called hydrogeochemical surveys. Groundwaters contain traces of metals leached from mineral deposits and rocks as they pass through pores or fractures, and from grains of rocks and minerals in soils. Waters of this kind can be sampled at springs, seepages, wells, and drillholes. Groundwaters are collected by streams, swamps, and lakes. The metal contents of such accumulations are diluted by run-off water, a fact that may make sampling undesirable after heavy rains or spring thaws. Work to date indicates that the elements most mobile in natural waters are, in order, sulphur, molybdenum, uranium, zinc, and copper, but many others have been detected. Metals are carried in solution and as minute particles of solids in suspension. The degree of solution is affected by the acidity of the water, the solubility of the elemental salts and other compounds, the presence of other elements and of organic matter, temperature, and other factors. Data on springs and seepages should be plotted separately from that of other sources, and studied with reference to underground circulation.

Water that enters swamps becomes stagnant and so may be enriched in metals. Detection may, however, be complicated by the presence of organic matter that prevents suitable tests or makes special tests necessary. The metals in swamp water are commonly precipitated in the sediments at the bottom or margin, making them especially favourable for sediment sampling.

The main use of water sampling techniques is in attempting to outline regional patterns of metal distribution. Even for this they are not generally as suitable as the sampling of stream sediments, but they may permit wider coverage. Samples of water are easier to collect than those of stream sediments, but when they cannot be tested fully by a portable kit they are more difficult to carry and to store. Anomalies indicated by water sampling may decay for various reasons explained in more detailed literature.

Water samples are difficult to handle. If allowed to stand, calcium, iron, and manganese may be precipitated and other trace elements may be co-precipitated or adsorbed. Acidification can cause solution of suspended trace elements. Filtration and acidification produce a more representative sample provided trace elements are not lost on the filter.

Canadian Surveys

Two experimental water-sampling projects in connection with uranium have been reported. Several years ago a study of the radioactivity of solids in the water of bays of Great Bear Lake and of smaller lakes near the Eldorado mine revealed a pattern. Although this suggested possibilities, the success of prospecting with Geiger counters caused little attention to be given to it. Later, Chamberlain collected more than 1,100 samples of water from creeks, lakes, and swamps in the Bancroft area of Ontario. Anomalous amounts of uranium were found only within a few hundred feet of known orebodies, but higher background levels were found over syenitic rocks with which many deposits are associated. He concluded that the greatest potential use of the method appeared to lie in outlining broad zones for other kinds of prospecting, and that its use as a guide to specific targets was restricted. The study also indicated that uranium is extracted from water by the reducing effects of decaying organic matter.

Gleeson made experimental surveys of water, stream-sediments, and heavy minerals in Keno Hill area, Yukon Territory. Nearly 8,000 samples of stream and spring waters were tested at the sample sites and 150 1-litre samples were tested in a laboratory. The results have been published in a series of fourteen maps. The manner in which the results are related to the known lead–zinc–silver deposits of the area suggests that the method is useful in prospecting under these conditions. Numerous anomalies were also revealed in areas that have been little prospected. Water and stream-sediment anomalies generally coincided, except for those of several springs where the ends of sediment anomalies were several thousand feet below those of water, apparently because of the acidity of the water. In an earlier study in the same district Boyle found that zinc was more readily detectable than lead or copper, but he pointed out that the known deposits there contain little copper. He found that many springs contained iron and manganese and concluded that the iron could be a useful indicator there and in other parts of Canada because iron is commonly present in non-ferrous deposits, but that it could also be insignificant where it had travelled far or had been derived from other sources.

Suggestions for Additional Reading

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1964: Hydrogeochemistry of uranium in the Bancroft-Haliburton region, Ontario; *Geol. Surv. Can.*, Bull. 118.
Describes an experimental survey, illustrated by a geochemical map.

Senftle, F.E.
1946: Relation of conductivity and total solid content of lake water to its radium content, Great Bear Lake region; *Trans. Can. Inst. Mining Met.*, vol. 49, pp. 439–446.
A pioneer experiment that indicated anomalies in bays of Great Bear Lake, and in small lakes, near the Eldorado mine.

Usik, L.
1969: Review of geochemical and geobotanical prospecting methods in peatland; *Geol. Surv. Can.*, Paper 68-66.

Wark, W.V.
1955: Geochemical prospecting in lakes and rivers; *Trans. Can. Inst. Mining Met.*, vol. LVIII, pp. 111–114.

SURVEYS OF VEGETATION

Plants absorb various chemical elements from the soils in which they grow. Some of these elements are necessary for the health of the plant; others are stored in different quantities in leaves, twigs, bark, or other organs. Roots absorb water in which elements are dissolved from the soil, and these are carried by the sap. Roots have complicated effects on grains of rock in soil, by which relatively insoluble chemical compounds are changed to forms that can be absorbed. Different plants have different nutritive needs, therefore certain ones absorb more or less of a particular element, even from the same soil. Observations on changes of these kinds are used as clues for prospecting based on vegetation. Studies of effects such as stunting and changes in colour, which can be observed directly, are the basis of *geobotanical prospecting*. Detection or measurement of one or more elements in plants, by means of analyses of ash, is the basis of *biogeochemical prospecting*. The latter has been more widely used and more successful than geobotanical prospecting.

Theoretically, surveys of vegetation may have several advantages over other geochemical methods. Samples are fairly easy to collect. Elements are accumulated over a long time, particularly by perennial plants. Roots of trees and shrubs extend through a fairly large volume of soil, and the amount of soil 'sampled' by a plant is greatly increased as the roots may absorb groundwater that has circulated through, and leached elements from, a much larger volume of soil than is represented by the root itself. One of the disadvantages is that the roots, even of large trees, commonly do not extend to sufficient depth to penetrate beneath layers of clay and clayey till, which may block the circulation of groundwater in still deeper soils. Another disadvantage is that samples for biogeochemical work must be reduced to ash in a laboratory, before analysis. A third disadvantage is the need for more research regarding the most suitable species of plants, and other factors.

Geobotanical Prospecting

For centuries observers have noted that certain plants thrived, were stunted, died, changed colour, or would not grow in certain soils or near certain kinds of mines. Such plants are called *indicator plants*, a term that should not be confused with 'indicator elements', which are discussed in a later section. It was hoped that indicator plants would provide visible clues that would form an important branch of prospecting, and long lists of indicators for specific elements were compiled in several countries. Few of the species proved to be reliable clues, however, because the observations were made in places where water or soil were contaminated by waste from old mine workings; this caused much greater concentrations of metals than would be expected to occur in soil or water over a mineral deposit. Geobotanical methods have not been used as extensively or as successfully as biogeochemical methods, but they hold some prospect for the future, particularly in connection with air photographs, where types of rock, if not of mineral deposits, may be indicated by changes in vegetation.

A paper by Shacklette dealing with variations in the colour and form of fireweed near uranium deposits at Port Radium is the only publication known to be related specifically to geobotanical prospecting in Canada, but unpublished observations are believed to have been made as well.

Biogeochemical Prospecting

Biogeochemical methods of prospecting comprise: (1) systematic collection of suitable samples from one or more appropriate species of plants; (2) preparation of samples, which generally includes reducing to dry ash; (3) analyses of samples, usually for very small quantities, by various spectrographic or chemical processes or combinations of them; and (4) statistical recording and studying of the results, commonly including plotting on a map or plan as for other kinds of geochemical surveys.

For biogeochemical purposes plant material may be divided into four groups that grade into one another: (a) bogs containing plant remains such as peat, which are discussed in this book in the section on surveys of water; (b) ground vegetation, such as moss, lichen, herbs, and shrubs; (c) larger vegetation consisting of shrubs and young trees, called 'understory vegetation' by foresters; and (d) larger trees, called 'overstory vegetation' by foresters. Many species of plants are not affected by the presence of abnormal amounts of an element in the soil, but others are. If the effect is a visible change it is considered to be related to geobotanical prospecting, but if the plant accumulates anomalous amounts of an element it has possibilities for biogeochemical prospecting. Most of the metals more commonly sought in prospecting have been shown, in certain environments, to be accumulated by some species in one or more of the four groups of vegetation mentioned above. Plants having deep roots are generally preferred, and first or second year growths of twigs are commonly selected. Most biogeochemical surveys in Canada appear to have been concerned with the leaves and bark of white birch, common willow, and the tips and second-year shoots of several conifers, but alder, cottonwood, soopolallie, horsetail, and probably other plants have been used experimentally. Douglas fir and lodgepole pine appear to have been the conifers most used in British Columbia.

Where a species being sampled is scattered sparsely, any individuals available may be sampled; otherwise samples are taken along lines, grids, or rectangular swaths, all having dimensions appropriate to the problem in hand. Pruning tools are commonly used for cutting samples. For some projects only one leaf or twig is taken from a plant, for others several are included in one sample, and for others a number of samples are combined to form a composite. Twenty grams of unprocessed material are commonly regarded as the smallest useful sample, but some experiments have indicated that still smaller amounts were sufficient.

Although biogeochemical methods have some potential advantages, stream-sediment sampling in Canada at present is more popular for reconnaissance, and soil sampling for detailed surveys. The Geological Survey of Canada is, however, continuing research in biogeochemistry. This includes

field investigations in the vicinities of certain known mineral deposits, experiments in a greenhouse, and efforts to determine the most suitable techniques for sampling, preparation, and analysis. The field work is designed to study the entire environment of certain deposits, by sampling rocks, soil, and various sizes and species of vegetation. Greenhouse experiments include studies of the way and degree in which certain plants absorb certain chemical elements, by adding to the soil specific quantities of an element.

Suggestions for Additional Reading

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1960: Botanical prospecting for ore deposits; *Science*, vol. 132, no. 3427, pp. 591–598.
A review of the subject.

Fortescue, J.A.C., and Hornbrook, E.H.W.
1967: Progress report on biogeochemical research at the Geological Survey of Canada 1963–66; *Geol. Surv. Can.*, Paper 67-23, pt. 1.

Shacklette, H.T.
1964: Flower variation of *Epilobium angustifolium* L. growing over uranium deposits; *Can. Field Naturalist.*, vol. 78, no. 1, p. 32.
The only known publication specifically on geobotanical research in Canada.

PATHFINDER ELEMENTS

Most ore deposits contain uneconomic elements as well as those that have economic potential. For some deposits one of these can be detected more readily by a geochemical method than can the metal or metals being sought. Guide elements of this kind are called *pathfinder* (indicator) elements. Warren and Delavault defined pathfinder elements as those "which because of some particular property or properties, provide anomalies, or haloes, more readily usable than the sought-after element with which they are associated". A pathfinder element should have a much lower background than the metal sought, and therefore provide a more conspicuous anomaly, or its manner of occurrence should be such as to permit easier sampling or analyzing than the metal sought. Surveys in various countries have shown several elements to be useful pathfinders for different kinds of deposits, but this does not imply that they would invariably be useful for similar deposits. Mercury has indicated silver, lead, zinc, and copper deposits; arsenic has indicated gold-bearing veins and cobalt deposits; silver has indicated silver-bearing gold ores; molybdenum has indicated copper deposits of the 'porphyry–copper' type; antimony has indicated silver–gold deposits; sulphur in the sulphate form may indicate deposits of sulphide minerals; and manganese and zinc may indicate gold and silver deposits. These instances of the use of pathfinders were mainly concerned with rocks and soils, but some were concerned with water. At present mercury is receiving most attention as a pathfinder element, mainly in connection with soil samples in places where outcrops are scarce.

Detection of Mercury

Mercury Haloes

Special attention is being devoted to the possibilities of mercury as a pathfinder element for two reasons: firstly, traces of mercury occur in dispersion haloes of many deposits, including many for which mercury would not ordinarily be thought to be an associate; and secondly, trace amounts of mercury are fairly easy to detect and to measure. The subject was first put forward by Saukov in 1946, and advanced by Warren, Sutherland Brown, and others. The methods used are also of probable value in actually searching for mercury deposits but the main emphasis is on pathfinder uses. Mercury tends to migrate upward rather than laterally from a deposit, perhaps because of the general outward circulation of heat from the interior of the earth.

A number of sulphide deposits of silver, lead, zinc, copper, and molybdenum have been shown to be surrounded by dispersion haloes containing a little mercury. The mineralizing process appears to have expelled mercury outward into the host rocks. Because of its mobility, mercury is readily released by weathering, forming secondary dispersion haloes in the soils. Attention is being given to the possibility of usefully detecting mercury in the air near deposits.

Detecting Instruments

For years a qualitative method of detecting the presence of mercury has been used with ultraviolet lamps. This consists of heating a sample of rock or soil, exposing it to ultraviolet light, and at the same time viewing the fumes through a special screen, which causes a characteristic appearance if mercury is present and if organic matter does not contaminate the sample. This principle has recently been developed into quantitative instruments of portable and laboratory types. A sample of soil or powdered rock is heated in a retort, the fumes are piped into a box containing a screen, provision for ultraviolet light, and a photoelectric cell that measures indirectly the amount of mercury in the beam and permits a reading on a dial. The laboratory types are not excessively large and could be used in a temporary laboratory if the latter were wired for electricity. Portable models, to which the slang name 'mercury sniffers' has been applied, are of about the size and appearance of Geiger counters. They are powered by a battery, and the sample is heated, by means of a propane torch, in a retort the size of a small egg. Some portable instruments cost about $200 and have proved useful under certain conditions but, even more than in the case of Geiger counters, they have to be used with discretion and by persons who understand the subject. Organic matter in a sample causes interference. Laboratory models are understood to permit more accurate measurements, to promote greater speed in analyzing large numbers of samples, and to eliminate interference from water vapour, sulphur dioxide, organic gases, and smoke.

Research in British Columbia

Although trials are being carried on in other parts of the country, most Canadian field research on pathfinder techniques has been done in the interior of British Columbia,

which contains a large mercury metallogenic province. Sutherland Brown has made surveys across several known deposits of silver, molybdenum, lead, zinc, and copper, and has published profiles for them. He used a portable instrument mainly for testing samples of soils, but also for samples of rocks. Surveys were made along roads and grids. The samples are understood to have been tested in camp or in mine buildings. His conclusions were as follows. The method was suitable for fairly detailed surveys, but not for reconnaissance of entire regions because stream sediments did not respond well to tests. Reconnaissance could be done along roads, and grids should be at intervals of not more than 1,500 feet. Samples should be dried in air, not heated. Careful measurement of the volume of material tested is necessary, organic matter should be picked or sieved from samples, the equipment must be kept clean and the retort must be re-heated thoroughly after use to prevent abnormally high values being obtained afterwards. Interference by sulphur could be eliminated by covering the sample with greaseless iron filings.

Warren and his associates have indicated that anomalous amounts of mercury occur in humus in the remains of some species of plants.

Suggestions for Additional Reading

Azzaria, L.M., and Webber, G.R.
1969: Mercury analysis in geochemical exploration; *Bull. Can. Inst. Mining Met.*, May, pp. 521–530.
Describes experimental surveys of the Pinchi fault zone in British Columbia using ultra-violet absorption instruments, including one modified with gold to remove interfering substances.

Sutherland Brown, A.
1965: Investigation of mercury dispersion haloes; *Ann. Rept. Minister of Mines and Petroleum Resources,* British Columbia, pp. 109–112.
An account of experimental surveys near known mineral deposits, illustrated by profiles.
1966: Some mercury soil profiles in British Columbia; *Western Miner*, vol. 39, no. 2, pp. 39–44.
A more recent discussion of the same subject.

Warren, H.V., *et al.*
1966: Some observations on the geochemistry of mercury as applied to prospecting; *Econ. Geol.*, vol. 61, no. 6, pp. 1010–1028.
Describes observations on mercury contents of soils and plants near mineral deposits in British Columbia.

PREPARATION OF SAMPLES

Containers

According to their kind, samples are transported or stored in small bags or envelopes made of canvas, plastic or paper, or in bottles which are preferably made of plastic (polyethylene). No container should be used more than once, to prevent contamination. Only one sample should be placed in a single container. Canvas bags are preferred for samples of rock because sharp corners may cut plastic or paper; if plastic or paper bags are used the pieces of rock should be wrapped with material that cannot add contamination to the sample. Damp samples should not be placed in canvas or paper bags. Plant samples can be dried conveniently in an oven in closed paper bags. Canvas bags are usually tied, and plastic bags should be sealed with waterproof cement. Useful paper bags or envelopes, similar to coffee bags, are equipped with strips of metal that are bent after the mouth has been folded a few times. Bottles are used for water, and plastic jars or bottles are preferred by some workers for stream sediments and material from bogs. All samples must be numbered, and some authorities prefer to write various other data on the container rather than in a notebook.

Drying

Most samples, including those of rocks, should be dried before bagging in camp or in a field laboratory. Drying is commonly begun or done completely in the sun, but drying in special ovens may be done alone or as a secondary treatment. Samples to be tested for a volatile element such as mercury should not be heated. The elements to be analyzed in samples of water are usually concentrated, either by evaporating the sample in a laboratory or by extraction with 'ion-exchanging' material at the time the sample is taken.

Crushing and Milling

Fairly elaborate equipment is required or desirable for processing all rock and many soil samples. All forms of preparation, as well as of analysis, require the utmost precautions against contamination, because of the trace amounts of elements usually determined. The equipment and procedures are described fully by Lavergne, the following being intended to cover only the main points. Rock is crushed to about ½-inch size in a jaw crusher, and then ground between ceramic plates to pass through a sieve having 10 meshes per inch. Soil samples may be treated in the same way if the material is coarse. Material that passes a 10-mesh screen is mixed by rolling many times between the corners of a disposable sheet of paper, and reduced to powder (finer than 150-mesh) in a ceramic-lined mill using ceramic balls. Unground soil or stream-sediment samples are used for some tests, but for others only material that has passed an 80-mesh screen is used. For spectrographic tests the processing of soil and stream-sediment samples to pass through a 200-mesh screen, and ashing to remove organic matter, is recommended. For some rock and soil samples concentration by panning, magnetic separation, or other methods is required.

Ashing

Most biogeochemical samples are converted to ash before analysis but, for some, separation of the desired elements by solution (solvent extraction) is used instead of ashing. Samples are usually dried in the sun or in an oven before ashing (dry ashing), but direct ashing of green material (wet ashing) is done in some projects. A special method called 'cold plasma ashing' provides oxidation by pure oxygen, without heating.

Suggestions for Additional Reading

Lavergne, P.J.
1965: Field and laboratory methods used by the *Geological Survey of Canada* in geochemical serveys, No. 8: Preparation of geological materials for chemical and spectrographic analysis; *Geol. Surv. Can.*, Paper 65-18.

ANALYSIS

The general principles of analysis are outlined in a section of Chapter 14. As the methods used in geochemical prospecting are based on these principles, the reader may benefit from reviewing that section before reading the following. Methods used in connection with geochemical surveys must be sufficiently sensitive to detect minute quantities of an element, accurate enough to avoid missing a significant anomaly, and economical enough to permit large numbers of samples to be tested at reasonable cost. Commonly, the methods must be simple enough to be performed by relatively untrained persons working under supervision, and be suitable for fairly portable equipment. In general, methods must be tailored, by close co-operation between the geologist and chemist involved, to suit each project. Consideration must be given to the elements to be determined, the way in which they are bound chemically in the sample and are associated with other elements, the ranges of concentration of elements to be determined, the number of samples, the availability of technicians and equipment, the cost, and other factors.

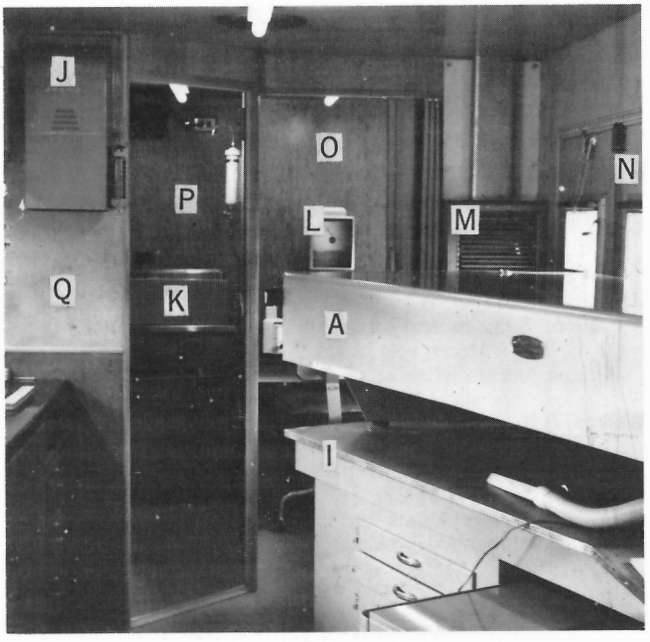
Many different methods and variations are used, and are described in other publications. Because geochemical prospecting is undergoing a period of rapid growth, methods are constantly being improved and modified, and completely new ones appear from time to time. An attempt to describe even one method in this book with sufficient detail to permit a beginner to use that test satisfactorily would be impracticable. The following outline is intended, therefore, merely to serve as an introduction to the kinds of testing most used at present, and to the publications listed.

In very general terms, the tests used are related to spectroscopy or to the colours of chemical compounds containing different amounts of a particular element. Spectrographic methods include *ordinary emission spectroscopy, X-ray fluorescence analysis*, and *atomic absorption spectrophotometry*. Emmission spectroscopy is useful where many metals are to be determined, and it may provide permanent records, generally in the form of films. It is, however, generally unsatisfactory unless operated by skilled technicians. The same can be said of X-ray spectographic methods, which have the advantage that the sample is not destroyed by the analysis. Atomic absorption spectroscopy has recently become popular for geochemical work because it is effective for both complete and partial tests and can be operated by relatively inexperienced personnel. Absorption spectrophotometry has, however, limitations that must be taken into consideration. Both emission and absorption instruments are now available in direct-reading types that indicate elements and quantities by means of dials or 'printouts' on tape.



R. H. C. Holman

Plate 67A. Mobile spectrographic laboratory. Y — water cooler, Z — water pump.



R. H. C. Holman

Plate 67B. Spectrograph room from rear of trailer. A — spectrograph, I — portable spectrograph stand, J — ventilation fan, K — photo-processor, L — densitometer, M — propane heater, N — double doors, O — densitometer room, P — darkroom, Q — spectrograph room.

Various concentrations of many elements dissolved in acid, water, or other solutions can be determined by *flame photometry*, or by observing or measuring the colour of

solutions either directly or after a dye has been added. Dithizone is commonly used for this purpose because it forms solutions having various colours after reacting with manganese, iron, cobalt, nickel, copper, zinc, palladium, platinum, silver, cadmium, tin, gold, mercury, and other metals. Also, rubianic acid has important uses.

Paper chromatography makes use of specially treated papers on which a little of the solution to be determined is painted. The element is indicated by the colour produced or by the position of the coloured reaction, and the amount is indicated by the intensity of colour and the size of the reaction on the paper. For determination of mercury and uranium, measurements of the fluorescence caused by ultraviolet light are commonly performed (*see* p. 205).

The quantities determined in geochemical analyses are generally so small that they are reported in parts per million instead of as percentages of the sample. To appreciate the meaning of 'parts per million', remember that 1 per cent is one part in one hundred, that 0.1 per cent is one part in one thousand, and that 0.0001 is one part in one million. Because of the large numbers of samples and analyses commonly involved in geochemical work, an analytical method is usually considered satisfactory if a large proportion of the results are accurate as compared with the results of a more precise method. Stanton states that rapid chemical analyses for geochemical purposes are satisfactory if 95 per cent of the determinations are within 25 per cent of the amount present, and that experienced analysts normally obtain results within 10 per cent.

Suggestions for Additional Reading

Cameron, E.M., and Horton, R.E.
1967: Analysis of rocks using a multi-channel emission spectrometer; *Chem. Geol.*, vol. 2.

Cruft, E.F., and Giles, D.L.
1967: Direct reading emission spectrometry as a geochemical tool; *Econ. Geol.*, vol. 62, no. 3, pp. 406–411.

Holman, R.H.C., and Durham, C.C.
1966: A mobile spectrographic laboratory; *Geol. Surv. Can.*, Paper 66-35.

Ritchie, A.S.
1962: The identification of metal ions in ore minerals by paper chromatography; *Econ. Geol.*, vol. 57, no. 2, pp. 238–247.

Shaw, D.M. (*Editor*)
1963: Studies in analytical geochemistry; *Roy. Soc. Can.*, Special Publ. no. 6.

Stanton, R.E.
1966: Rapid methods of trace analysis; London, Edward Arnold.

Warren, H.V., *et al.*
1953: Acetonic dithizone in geochemistry; *Econ. Geol.*, vol. 48, no. 4, pp. 306–311.

Profiles, Plans, and Maps

Geochemical data are usually plotted, either for private purposes or for publication. Results obtained along isolated straight traverses, are commonly plotted as profiles (*see* Fig. 35). Results obtained along a stream are commonly shown by dots or numbers or both on a plan or map, or as shaded or otherwise accentuated parts of streams (*see* Figs. 36 and 37), or by 'profiles'. Results of grid-surveys are commonly plotted on a plan or map. For elaborate surveys, one or more 'working' or 'data' plans or maps may be prepared to provide information for an 'interpretation'

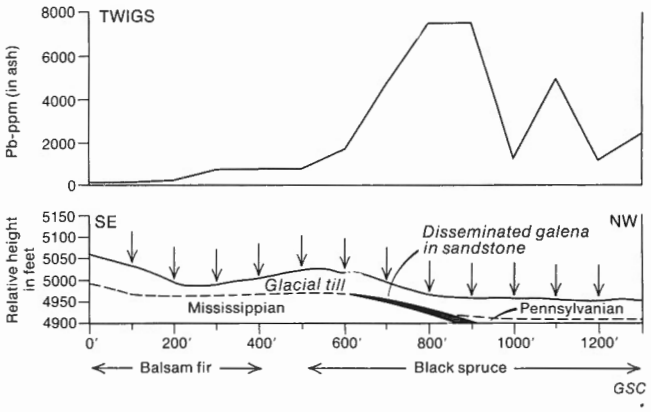


Figure 35. Profile showing lead content in twigs above and near lead deposit occurring as illustrated in lower part of diagram, Cape Breton, N.S. (after M. Carter, M.Sc. thesis, Dept. of Geology, Carleton University, 1965).

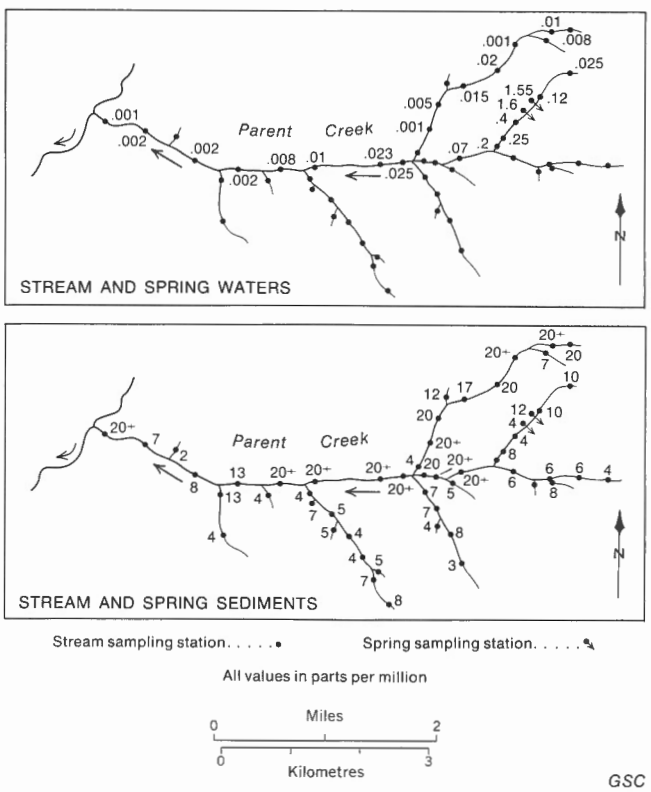


Figure 36. Heavy metal content (mainly zinc) in stream and spring waters and stream and spring sediments, shown by sampling stations, Keno Hill area, Yukon Territory (after Gleeson *et al.*, Geol. Surv. Can., Maps 20-1964 and 21-1964).

plan or map. Different colours or symbols may be used for indicating different elements on a single sheet of paper, and ranges in quantity may be indicated by the sizes of dots or other symbols. Alternatively, maps for individual elements may be prepared, either on opaque paper or on transparent overlays. Some plans and maps are 'contoured' in a way resembling topographic contour maps, and areas between contours may be accentuated by colouring or patterning.

The results of geochemical surveys commonly cannot be interpreted satisfactorily by statistical study or plotting alone. Consideration of the topographical and geological features of the area are usually necessary.

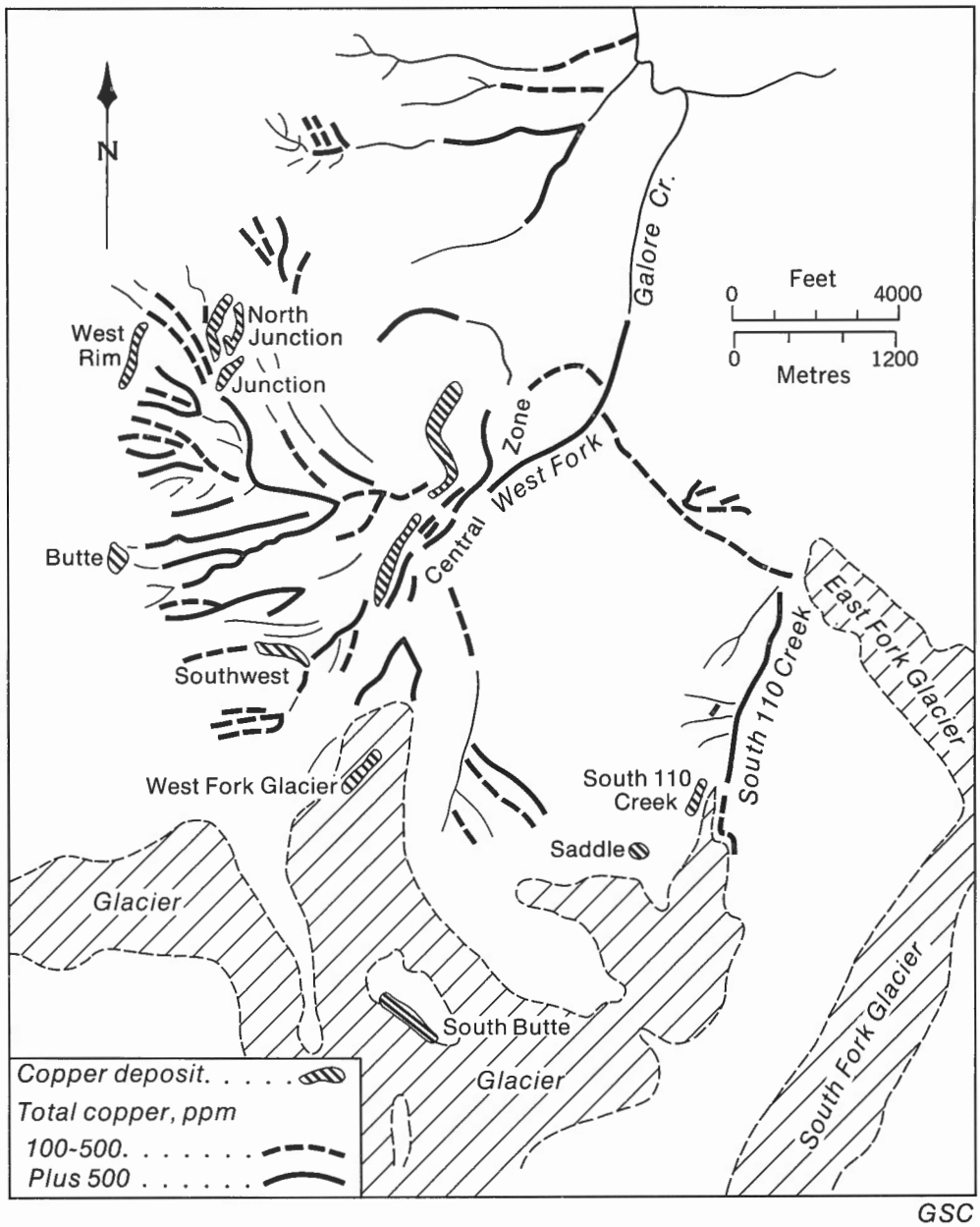


Figure 37
Stream sediment survey shown by two symbols for anomalies, Galore Creek, B.C. (after D. A. Barr, *Trans. Can. Inst. Mining Met.*, vol. LXIX. 1966).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14 judging and testing mineral deposits

The full appraisal of mineral deposits and mining properties is a technical matter that may involve the expenditure of much time and money. Even after this, uncertainties often still remain, because most deposits have variable shapes and erratically distributed minerals. There is probably no other industry that uses more advanced engineering and scientific methods for the solution of its problems; yet many prospects and mines have characteristics that are not fully known until after a deposit has been completely mined out.

Except in the earlier stages the judging of deposits is, or should be, the work of mining engineers with operating and geological experience or of geologists with engineering background, and it is not the purpose of this publication to discuss these matters to that extent. Prospectors should, however, have a sound knowledge of the fundamentals, to assist them in deciding whether a discovery is worth preliminary work and, if so, the form such work should take. It would be impossible for companies to send an engineer or geologist to examine every occurrence found by independent prospectors, even if it were practical to do so. Prospectors must therefore be able to make the first decisions themselves and to do preliminary work on the more promising finds, and prepare a simple but meaningful report for their backers or the persons they hope to interest. Prospectors should be able to carry the judging and testing a few steps further if necessary. Knowledge of these matters will also help them to decide whether a 'deal' is reasonable and it will be useful to those who back prospectors or participate in mining ventures.

Few, if any, mineral deposits are obviously of commercial value from their first discovery, and few are so obviously valueless that they can be dismissed without any study at all. Most must be judged and explored in a series of steps that result in a process of elimination. Judging and testing are closely related but are discussed separately here for easier understanding. The steps that a prospector must or may need to take himself are mainly described first, and later steps that may be undertaken by other persons on the more attractive discoveries are described later and in less detail, to provide an idea of this aspect of the subject. With regard to sampling, however, all methods are described first and those that a prospector might use are indicated later.

JUDGING DISCOVERIES

Like all industries, mining is based on economic principles, some of which are applicable to business in general, whereas others are peculiar to mining. The basic principles are, first, that mining is the business of producing and marketing minerals, ores, and metals and, second, that this business is governed by the law of supply and demand. Strictly speaking, supply is the amount that will be offered at a particular price, and demand is the amount that will be bought at a particular price. In a more general sense, supply and demand is the interaction of several separate streams of supply and several origins of demand. These result in continuing changes in availability and requirement for mineral commodities and, occasionally, wide fluctuations in prices. At times it may be almost impossible to interest a company or financier in a discovery of a particular metal or mineral, even if the size and other factors are promising.

A condition peculiar to mining (including the oil and gas industry) is that it is based on a single 'crop'. When an orebody has been mined it is exhausted forever; therefore financing must be done with this in mind. Capital invested in acquiring, testing, and equipping a mine can be recovered only from the profits of the operation or from sale of the property or plant.

Another peculiarity of mining is the large number of insignificant mineral occurrences as compared to the number that will repay the cost of mining. Nature made mineral deposits in all shapes and sizes but, as a rule, only the larger or richer are valuable. The smallest can usually be dismissed at a glance, but larger ones, which are called *prospects* because they show some prospect of being of commercial size and mineral content, or of leading to something better, almost invariably require expenditure of time and money to determine if they have merit. To decide this is a complicated matter, because deposits are seldom well exposed at the surface, and even when they are their subsurface characteristics are still unknown. Mineral discoveries are therefore subjected to a process of elimination whereby prospectors choose those that they hope can be classed as prospects, and do a little work on them; then scouts, engineers, or geologists representing investors examine a large number of such discoveries, select the better prospects for further preliminary exploration, and gradually eliminate the poorer ones and continue to test the more promising ones. By the time a mine reaches production it is not uncommon for one or several million dollars to have been spent in exploring and equipping it, to say nothing of the money that has been spent in exploring other properties that did not yield favourable results. A would-be prospector should not feel discouraged at this state of affairs, for the mining industry flourishes in the face of these disadvantages; a reasonable sum can often be obtained for a good prospect, even though it does not later live up to expectations on exploration, whereas the return from a successful property may be very substantial. Allowance must be made, however, for the fact that many discoveries will probably be unimportant. The following sections outline the principal factors that must be considered in estimating

the possibilities of a discovery. In most cases, either the size or the content will prove unfavourable, and the remaining factors need not then be considered. The general principle of the old saying that one in one hundred occurrences is a prospect and one in one hundred prospects is a mine is sound, although the exact ratios are unknown.

Most examinations consist of two kinds of judgments. The first is concerned with obtaining adequate estimates of size, content, continuity, and other such matters. The other involves trying to decide whether the general environment, indicated by the kinds of minerals, rocks, structures, and other geological features, is favourable for the presence of a substantial deposit. The second aspect is largely a matter for geologists, but prospectors and other mining men commonly need practical knowledge of it. One authority recommends that, if a geologist is unfamiliar with the district where he is to examine a prospect, he should, if possible, study it in general for as much as two weeks.

Size of Deposits

Of all the factors that determine the worth of a prospect, the size and average grade are usually the most important. Productive mines range from 'pocket' deposits, from which a few tons of high-grade ore are mined, to enormous operations involving many thousands of tons of ore daily for many years. Pocket mines are usually worked by only one man or a few men, and must be conveniently located to transportation unless the product can be easily moved, as with gems or free-milling gold. At the other extreme, deposits that will support the largest operations are exceedingly rare. Almost all producing mines are between these extremes of size, and are operated at rates of 100 to 5,000 tons per day; most are smaller than 2,000 tons per day. Ores mined at these rates are usually too lean to make shipping in the raw state profitable, so it is almost always necessary to build at the mine a plant for concentrating the ore to a partly or completely processed product. Fairly simple plants, of 100 ton-per-day size, may cost $100,000 or more, and large complex ones may cost several million dollars. The most conservative practice is to postpone mining until an amount of ore sufficient to repay the cost of the treatment plant and other equipment from estimated earnings has been proved, but the cost of providing such information and the time required may be prohibitive. It is, however, generally considered to be sound practice to go into production when ore sufficient for three years' operation has been proved, provided that the geology is sufficiently favourable that it is likely that a great deal more ore will be developed as mining progresses. In other words, if the deposit is known, or is considered likely, to pinch out at the sides and at depth, a plant would be justified only if the deposit were proved to contain enough ore to repay the cost, but if the deposit appears to continue beyond the part that has been proved to contain three years' ore, and if the geological conditions seem favourable for substantial extension, it may be reasonable to take a chance even if the three-year block of ore would not pay for the plant and other capital expenditures. Some mines have been operated for several decades without having had proven reserves of ore for more than two to five years at a time, but their geological probabilities were unusually good.

Ores that consist chiefly of quartz or other fairly light minerals average about 12 cubic feet to a ton, ores in which metalliferous minerals are fairly abundant average about 10 cubic feet to a ton, and massive metalliferous ores average still less. Three years' ore for a 100-ton plant represents about 110,000 tons, or about 1,300,000 cubic feet. If this orebody were a vein 3 feet wide, traced for a length of 1,000 feet, it would have to be proved to extend consistently to a depth of about 430 feet to comprise three years' ore averaging 12 cubic feet per ton. However, all mines do not operate on a single deposit; several smaller deposits may be mined if they are spaced within a few hundred feet of one another, but in such cases the costs of exploration and mining will be higher per ton than if the ore were in a single body.

A discovery that does not appear to have possibilities of being proved to contain at least 100,000 tons will be unlikely to merit attention unless it is very rich or possesses other unusual characteristics. This means, for example, that if the showing is 3 feet wide or more, seems to contain a reasonable amount of valuable minerals, and its length is obscured by overburden, it is worth stripping or trenching to test whether it extends for several hundred feet, and, if so, may later be worth exploring at depth to learn if it extends deep enough to make up the required tonnage. Some deposits pinch out or are offset by faulting a short distance below the surface, and some others persist to great depths; in general there is reason to hope that they will extend at least half as far in depth as they do horizontally.

In the examples mentioned above, widths of 3 feet were mentioned. This was done because 3 feet is about the narrowest practical underground opening, and therefore most deposits have to be at least 3 feet wide to permit profitable mining. If they are narrower, some waste rock will have to be mined as well, and so the deposit would have to be richer. A few deposits, such as high-grade gold, native silver, and pitchblende veins may be mined, even if only a few inches wide, by removing 2 or 3 feet of waste rock alongside, but deposits rich enough to warrant this are exceptional.

Before a small 'showing' is abandoned, consideration should be given to the possibility that it might improve greatly with depth or laterally, or that it might be an independent outlier to an important deposit. This is always the prospector's dream, and it proves correct in some instances, but many other deposits become much smaller or die out altogether a short distance along or below the surface. Most deposits remain about the same; if they are short and narrow at the surface they will probably be short and narrow in the third dimension; if a series or cluster of small lenses is found at the surface, their downward continuations will probably be small and lenticular as well. There have, however, been notable examples in which small, relatively insignificant surface showings proved to be the upper manifestations of important deposits. In some cases the surface showing was part of a large body, barely unroofed by erosion. In others a cluster of deposits lay like a hill of potatoes,

distinct from one another, and the surface showing was merely a small member of the cluster. Such remarkable discoveries are comparatively rare, however, and it would be absurd to do expensive testing along or under every little mineral occurrence in the hope of obtaining marked improvement. It is a justifiable gamble only when the general geological conditions in the vicinity of a small showing are particularly favourable: for instance, if the showing is in or near a strong fault or shear zone, or in a large zone of alteration of a kind that is associated with important deposits elsewhere, or in a particular rock such as a bed of limestone in which important deposits are known to occur in another part of the district.

Mineral Content

Those who have never seen a mineral deposit usually think of one as composed of solid, pure metal or as a solid mass of some mineral such as galena. Nothing could be farther from the truth, for even the richest deposits almost invariably consist of a mixture of minerals. In most deposits the valuable mineral or minerals constitute but a fraction of the whole, and are usually distributed unevenly, in small grains and masses. In many deposits these grains are microscopic in size, and fairly large masses of what appear to be a pure mineral are seen, when examined under a microscope, to contain minute grains and threads of other minerals.

The valuable content of a deposit is called its *tenor* or *grade*. The former term is preferable because 'grade' also refers to slopes, but 'grade' is much used. The content of gold and other highly valuable metals is expressed in 'ounces per ton' of ore, whereas the amount of base metals is expressed as a percentage. Some industrial minerals are expressed as percentages, and for other kinds of deposits special terms are used. Because deposits are variable, the grade can be estimated properly only by averaging the results of many samples that have been taken in one of the ways mentioned later, and have been carefully analyzed or otherwise tested, but in the earliest stages a prospector must generally base his opinion on a few samples taken for panning or assaying. The feasibility of assaying and the number of samples depends on the ease of getting samples out and reports back, and on the cost of assays.

Most deposits are far from uniform. Some consist of low-grade and high-grade parts that, in the aggregate, have sufficient value to permit mining the entire deposit. Others contain parts, called *ore shoots*, that are mined, the intervening parts being too sparsely mineralized to be mineable. For many deposits, an average value that permits profitable mining is determined; parts of the deposit may have a higher tenor than this average, in which case rock below average tenor is mined for blending with the higher grade material. The tenor of the lowest grade material that can be mined economically in that particular deposit is called the *cut-off point*. Ore whose grade is just at the cut-off point or slightly better is called *marginal ore*, and material that is slightly below the cut-off point is called *sub-marginal material*. An improvement in price or operating costs will sometimes cause sub-marginal material to become ore. One of the first matters that a beginner must learn is not to get excited over minute quantities of metals or other elements reported in assays or analyses. Most rocks and minerals contain many elements in small quantities, usually too slight to be significant.

Estimating the grade of a deposit fully is a highly technical matter. It is generally done with more and more precision as exploration advances. The estimates made by a prospector on a discovery, and by an engineer or geologist on a raw prospect, must be adequate, but they do not need to be as precise as those on a prospect that has responded to exploration and is being evaluated as a possible producer. A prospector needs to know enough about the subject to permit him to decide whether a discovery is worth further consideration. He can form an idea of this from the ore grades of producing mines. As a rule, the larger deposits permit the mining of lower grade ores, because costs decrease as the volume of business is increased, and a large uniform deposit of moderate or even fairly low grade is usually preferable to a small rich one, particularly if the latter contains erratically distributed minerals. Most gold ores being mined in Canada at present have values of $10 to $25 a ton, and most companies also receive a special subsidy on gold. The ores of most base metal mines now average from 1 to roughly 10 per cent copper, lead, zinc, or combinations of these metals, but some large low-grade copper ores average less than 1 per cent.

Other Geological Characteristics of the Deposit

Besides size and grade, and the non-geological considerations mentioned later, other features of a deposit may influence its possibilities. These are chiefly related to the geological type of the deposit and to its structural features.

Some types of deposits have a good reputation for size and persistence, and others have not. For example, stratified deposits such as coal seams, sedimentary iron ores, and bedded rocks used as industrial minerals are likely to have a fairly even grade and to extend for substantial distances. Replacement deposits also have a fairly good reputation because, although many are small, many others are large. Also, they may occur in clusters, so that if one is found, others commonly lie nearby. Veins are of many sizes; small ones are not likely to extend for long distances, but large ones have a good chance of extending both laterally and downward. Pegmatite deposits are generally fairly small, and any valuable minerals they contain are likely to be distributed erratically. Although there are exceptional pegmatitic deposits, most are worked on a small scale, if at all, or as swarms of closely spaced deposits. If other deposits of the same type as the one being considered have been explored or mined in the same region, the conditions encountered there should be ascertained and considered.

It may be vitally important to consider whether a surface showing represents primary or supergene mineralization. Supergene minerals do not, as a rule extend far below the surface in Canada. These minerals may be concentrated at or near the outcrop of a primary deposit, as a result of long-continued solution and deposition by surface waters, with the result that the near-surface part of the deposit is

much richer than the main primary part. On the other hand, the upper parts of a few deposits have proved to be misleadingly lean, because primary minerals were dissolved and carried away by surface waters. Full interpretation of these matters must usually be left to geologists, but competent prospectors should be able to recognize the possibilities and problems sufficiently to form a preliminary opinion about them.

Structural features often influence the economics of a deposit by determining its dip, by causing weakness of the deposit itself or of its walls, or by causing it to be displaced by faults. The lowest mining costs are obtained in large deposits that have considerable lateral extent, thus permitting them to be mined by open-pit methods employing power-shovels, draglines, or bulldozers. The ore is removed from the pit by large trucks, by aerial tramways, or, in the largest operations, by standard-gauge railways that spiral around the sides of the pit. Examples of deposits worked by open-pit methods are flat-lying or thick coal seams and other sedimentary deposits, and the upper parts of large replacement and contact metasomatic deposits. Fairly cheap underground mining can be done on deposits that are large in all three dimensions. Bodies such as veins, that are relatively narrow compared to their other two dimensions can be mined fairly cheaply if they dip steeply (say, 50 degrees or more), because mined ore then moves by gravity in the stopes and ore passes, until it is collected at a convenient point for haulage or hoisting. On the other hand, it is usually more costly to mine a fairly flat-lying vein because the broken ore has to be handled by some mechanical method such as scraping. Structural or stratigraphic features that affect the strength of ore or wall-rock may add greatly to the costs of mining because much timbering and back-filling may be required to support ore or rock weakened by fracturing or faulting. In the same way, timbering may be required if the rock immediately above an orebody is inherently weak, apart from structural conditions. If a deposit is displaced by faults, costs of exploration and mining will probably be greater.

Location and Transportation

As is to be expected, location has an important bearing on whether or not a prospect can be explored readily and whether a mine can be operated economically. Apart from the question of transportation, if a deposit is in a settled area it is easier to obtain labour, and any amenities available make it easier to hold labour and lessen the need for housing, recreation, and other facilities to be provided by the company.

Topography plays an important part in determining the cost of exploration and mining, because adits (tunnels) cost much less than shafts. If a deposit occurs in a mountainous or very hilly setting, the entire deposit or its upper part is usually explored and mined from an adit. This is customary in the Cordilleran region, but shafts predominate in other parts of Canada because the relief is usually too slight to make adits practical.

Transportation facilities and availability of developed or potential electric power are most important considerations, both in the exploration stage and in the event of production. Any but the most preliminary exploration requires considerable supplies and equipment, and before substantial production can be begun large amounts of heavy machinery, building materials, and other supplies are needed. In addition to these, an average of about thirty-five pounds of supplies is required for each ton of ore produced. Finally, there is the problem of getting the product to market. In the parts of Canada served by railways, highways, or established water routes, transportation is fairly easy, although freight charges may add appreciably to the costs of exploration and mining. Beyond established routes, where exploration must be serviced by air or by tractor trains, costs rise greatly; to be attractive, therefore, a prospect has to be better than it would be if it were in a more favourable location. A few, chiefly gold, mines have become productive in remote places without the provision of highway or rail transportation, because they were sufficiently profitable to warrant transport of heavy equipment by sleighs and tractors during the winter, and the shipment of the output by air. In almost all instances, however, it has been necessary to provide road or rail links before production could begin. This has meant that deposits even a few miles from major transportation facilities had to be considerably better than if the facilities had been available already, and that deposits in very remote places have had to be good enough to warrant extension of facilities; if such facilities could not be provided, the deposits have been left unworked. Transportation costs also cause material, which would be classed as ore in central Ontario, to be classed sub-marginal at mines such as those at Yellowknife and Beaverlodge.

Treatment

In special circumstances ores may be shipped to market in the state in which they are mined, or after sorting by hand. In most instances, however, treatment plants are required. This applies even to most coal mines, which are equipped with screening and washing plants, and to many iron mines, where preliminary treatment is carried out before the ore is shipped. Most mines have elaborate plants for crushing, grinding, and concentrating the ore, and some are equipped with special chemical or smelting plants that carry the processing through all stages except final refining. In some instances a plant already operating in a district will accept suitable *custom* ore from neighbouring mines. In view of the great differences in ores, however, it is usually necessary to provide individual plants, after careful research has been done on bulk samples. The kind of treatment necessary, the percentage of recovery that can be expected, and the ease or difficulty of treatment all affect the cost of operation and influence the decision as to whether mining is practical. If other factors are favourable, a satisfactory method of treatment can usually be worked out, but if a deposit is in a remote place, or seems just large and rich enough to be mineable if there were no complications, or if its ore is costly to treat, or permits only poor recovery, it is likely to be regarded unfavourably. One should not be too pessimistic about treatment, however,

because advances in methods may become available. For example, a large Canadian mining organization instructs its field staff never to turn down a property on the ground of treatment alone. If other factors are satisfactory, but treatment presents a problem, it will try to develop an improved method of treatment.

Present and Future Demand

The state of the market for a particular metal or mineral is an important consideration. Many of the base metals, such as iron, copper, lead, and zinc are normally in such demand that good deposits are almost certain to be valuable, although their prices fluctuate considerably. Demand and prices for other mineral products for which there is a more limited market need to be considered very carefully. In other instances, there may be no present market, but there may be hope that a market will be available in future, or that a market could be developed if a large deposit were shown to be available.

General information on prices and demands are included in Chapter 15 but this cannot be completely up to date. More recent information can be obtained from the mining press. It should be emphasized that for many metals the prices usually quoted are trade prices for products of smelters and refineries. When ores or concentrates are shipped to a treatment plant the prices paid for the contained metal are considerably lower. In the first place, nothing is paid for metals that cannot be profitably extracted, and a penalty may even be charged for the presence of objectionable components that make the extraction of others more difficult. Plants deduct a certain amount as a treatment charge and privately owned ones try to make a profit. Finally, the prices for many metals are based on the New York or London markets, so a Canadian plant may have to allow for the cost of freight, duty, insurance, selling, and perhaps refining. Such matters must be considered carefully by engineers in appraising a deposit. A prospector does not have to consider all the details, but when judging a new discovery he should make allowances for the probable demand, and for the possibility of considerable spread between the value of ore and the published quotations for metals and minerals.

Prospectors sometimes form misleading opinions of the value of discoveries by assuming that all the constituents shown in an assay or analysis can be recovered profitably. For some ores it is possible to count on obtaining payment for most of, say, gold and copper, or lead and zinc, but only in exceptional cases is it possible to recover metals or minerals occurring in minor amounts. The possibility should be investigated eventually, but it is seldom important at the outset, when the decision to do preliminary work should be based on one or two principal constituents.

TESTING DISCOVERIES

A discovery that shows signs of being of possible importance must be tested before its worth can be judged. Apart from the fact that nothing can usually be learned about the conditions at depth without some form of subsurface probing, few occurrences are sufficiently exposed to allow appraisal of their width, length, and possible mineral content without the removal of overburden and products of weathering from all or parts of them. Work done to reveal the extent and content is properly called 'exploration', but as this word is used in some publications for special methods of prospecting, 'testing' is used here to avoid confusion. The term 'development' is sometimes used, but it is more properly used in connection with the preparing of a mine for production, after an orebody has been proven.

The earliest testing is usually done by the prospector himself on any occurrences that he thinks warrant it, so as to judge their importance, and to provide exposures for examination by an engineer or geologist. Further work is usually financed by companies on recommended prospects. The first of such additional investigations may be done entirely by a company, or it may finance the prospector and tell him how to proceed. This is all part of a process of elimination, whereby prospects that respond to preliminary testing are examined, and further work is recommended or not as the case may be. After each favourable report, more advanced exploration is done until finally a few mines are brought to production, out of a large number of prospects on which money was spent but which did not respond. This process usually requires several years; few mines reach production until at least three years after the initial discovery, and in recent years the average has been six and one-half years. The aim is not to risk too much in the early stages, but to re-appraise the situation periodically, and to risk more and more money on those prospects that seem to warrant it. The trend today is for prospectors not to undertake more than the first step or two unless they cannot obtain financing but have enough faith in a prospect to do further work themselves.

Testing by the Prospector

After a discovery that may have promise has been found, the first step is usually to try to get a general idea of its width and length. Before any work with tools is done, other than picking into the outcrop to try to obtain fresh specimens, it is usually advisable to make a reconnaissance, because the width and length may be determined well enough from other exposures to avoid the need for removing overburden, or because the reconnaissance may indicate where work can be done to best advantage, or because a better deposit may be found nearby.

The true width or thickness for any particular section of a deposit is the distance at right angles to both the strike and the dip (*see* Fig. 3). If the deposit dips vertically, the width measured horizontally and at right angles to the strike will be the true width. If the deposit dips at an angle, the width measured horizontally will be greater than the true width. This is an important consideration because the surface showing of a deposit often gives an exaggerated impression of the width, particularly if the dip is fairly flat. Also, although a few deposits maintain regular width, most widen and narrow, and it is then necessary to determine their average width.

The length of a deposit is the distance it extends along its strike. When attempting to trace the length it is important to understand the way in which the outcrops of a dipping deposit are distributed with respect to a sloping or irregular land surface. If a deposit dips vertically, its outcrops will occur in a straight line regardless of how irregular the surface is. If the dip of a deposit is inclined at an angle, and the land surface is flat, the outcrops will lie in a straight line; but if the land surface is sloping, the outcrops will trend down the slope in the direction of the dip of the deposit. This is difficult for a beginner to visualize, but after a little practice he learns to think in three dimensions and to take into consideration the slope of the land surface. It is useful to experiment with a model made of sand, mud, or plasticine. A sloping surface or a series of hills and valleys can be shaped on the model. Then, if a piece of flat cardboard is taken to represent a vein or bed of rock, it can be thrust into the model at different angles. The line of juncture of the cardboard and the surface of the model will then illustrate the manner in which the outcrops of a vein or bed are distributed with respect to the surface.

When attempting to trace the length, if the dip or surface is such that the outcrops should follow a simple line, it is easy to take a bearing and follow it in the hope of finding other outcrops. If not, allowance is made for the 'swing' of the outcrops and a search is made in appropriate places. In open country, a row of pickets or piles of stones can be set in line by sighting along two already in place. In wooded country it is useful to blaze a line, and clear it if necessary, as this will not only assist in directing the search for other exposures, but will be useful later when making a rough survey of the showings. All that has been said above regarding the trend of a deposit assumes that the deposit has a regular strike. Many deposits, however, are inherently curving or irregular in strike, apart from any swinging of outcrops due to dip and land surface.

If the width and lateral extent of the deposit are not sufficiently exposed in the natural state, a limited amount of work is usually done by a prospector to try to improve the exposures. In the simplest cases this may involve only the scraping away of moss or thin overburden (*see* Pl. 68). If necessary this is supplemented by digging trenches to try to reach bedrock. Preliminary trenching is commonly done at intervals of 25 or 50 feet, the trenches being placed at right angles to the strike. If bedrock cannot be reached at a depth of about 5 feet, it is customary not to go farther, at least in the early stages of exploration. In some instances an iron bar or pipe, or a post-hole auger, can be driven into the ground to learn the depth of bedrock, but this is not practical if the overburden contains large boulders. Special bars with a device at the end for holding fragments of rock are sometimes used to learn the character of the bedrock without the necessity of trenching. Probings of this kind, or the presence of outcrops, may indicate that trenches will reach bedrock more advantageously at a different place than by even spacing.

If the deposit is revealed in an outcrop or trench, it is useful to place a stake, picket, or pile of rocks to mark one of its walls, or the centre of a narrow deposit, and to place others along the strike, to assist in locating other trenches, making allowance for dip if necessary.



H. C. Gunning 81955

Plate 68. A quartz vein with the overburden stripped off, and a little rock blasted out where the depressions are filled with rainwater. Note shearing of wall-rock at side of vein.

Trenching is usually continued, if the exposures thus found show reasonable widths and mineral content, until the prospector believes that he has established enough length to interest an examiner. He would not have to establish a length of many hundreds of feet at the outset, if the width and mineral content are impressive. If the deposit seems to end in one direction, it is desirable to do some further stripping or trenching in the vicinity to try to learn if it actually dies out, or if it is faulted, or if branches or parallel bodies can be found.

Trenches should extend a foot or more beyond the walls of the deposit, to indicate the nature of the wall-rocks and to make sure that no additional stringers or other mineralized material are present. If a deposit is very wide, all preliminary trenches do not have to extend the full width. Instead, pits can be spaced at intervals across the width.

In places that are favourably situated, stripping of overburden can sometimes be done to advantage by using water under pressure from a portable fire pump (*see* Pl. 69). In another method, known as ground sluicing, a small stream of water diverted to the desired place by a ditch can be allowed to flow until it washes off the overburden. If the amount of water is small the effect can be increased by what is called 'booming' (*see* Pl. 70). A small dam is improvised at a convenient place and a gate a foot or two in size, made out of boards or hewn logs, is placed in the dam. The gate is opened from time to time, to allow the pent-up water to rush out; or an automatic gate may be built by hinging it and arranging a latch that is opened by a lever, at the other end of which is a box into which water flows when the pond is full.

If the deposit contains radioactive minerals it may be possible to trace it beneath a few feet of overburden by using a Geiger counter or other detector. Similarly, if a



A. H. Lang 5-6-1949

Plate 69. A portable fire-fighting pump used to cut trench through overburden and to clean bedrock.



W. E. Cockfield 44088

Plate 70. A crib-dam and boom-gate used as an aid in removing overburden.

deposit contains magnetite or pyrrhotite in sufficient quantity, it may be traced by using a dip needle.

As trenching proceeds, the deposit should be constantly reappraised as there is no point in continuing to do work if the deposit seems to be too small or of too low mineral content. Preliminary panning may be done as exploration proceeds, and samples should be sent for assay if possible.

Next, it is necessary to consider whether the prospector should blast into the rock. Many deposits are too weathered to permit the prospector or examiner to obtain a satisfactory idea of them unless openings are made by blasting. On the other hand, many prospectors do not know how to use explosives safely, or do not have the necessary equipment. Although it is not necessary that all prospectors should be able to undertake 'rock work', it is explained in a later section. If the surface is badly weathered, and if the knowledge and equipment are available, it is often desirable to blast into the surface of the deposit at a few places, using the methods described in another section. This can be done by placing a few 'pop holes' or rock trenches in a few outcrops of the deposit, or in the bottom of a few trenches dug in overburden. It should be emphasized, however, that in general only enough removal of overburden, or blasting, should be done at first to provide sufficient information to interest possible backers or buyers and to facilitate the first professional examination. Examiners often find that a prospector has not done enough work, and that their trip has been largely a waste of time; but they also often find that a prospector has done too much misdirected work, such as extensive trenching in a poor location, or unnecessary surface blasting, or even unnecessary tunnelling.

The last preliminary step, often overlooked, is to make a rough survey and sketch showing the position and nature of outcrops of the deposit and nearby rocks, the position of trenches, if any, the numbers and positions of specimens and samples, and the locations of trails and other features.

This completes the preliminary work. The next step is usually to try to interest capital, or to go on with general prospecting until an examination can be arranged. In some instances, an examiner who did not recommend that his principals acquire the property or finance further work, might suggest that the prospector do further work of a certain kind himself. In other cases, the prospector might need to do assessment work on the claims in another year, and so would do further exploration on the deposit. He would then proceed with some of the earlier stages of advanced exploration, as described later. If possible, he should obtain professional advice before undertaking such work, unless he is very well qualified, because mistakes at any stage beyond very limited preliminary exploration are costly, and because he might better occupy his time in trying to find other deposits.

If a deposit contains significant amounts of radioactive minerals, blasting usually scatters fragments in such a way that Geiger counters or other radioactivity detectors cannot be used dependably for further prospecting in the vicinity or for testing showings. It is, accordingly, better

not to blast until after any desired radioactivity surveys have been made, or, if it is necessary to blast to try to expose primary parts of the deposit, logs may be laid above the part to be blasted, to minimize scattering.

Examiners who turn down properties are usually generous in giving advice on work the prospector might do to improve his showings. Also, several provincial government departments employ engineers or geologists who do as much as possible to advise prospectors, although they cannot visit all properties in their districts each year. Furthermore, geologists of the Geological Survey of Canada are glad to advise prospectors and claim owners when they visit properties in an area being mapped, or when making special studies. Federal agencies do not, however, make special trips to examine properties at the request of, or on behalf of, the owners. Failing any of these ways of obtaining advice, a prospector or his grubstaker should consider the advisability of engaging the services of a consulting geologist or mining engineer. Some prospectors cannot afford this, but others who can will spend thousands of dollars on their claims in other ways, without spending a hundred or so on professional advice.

Sampling

One of the most important skills of a prospector is to be able to take samples that are sufficiently representative of a deposit. Almost always, one or more samples must be taken from each discovery that seems to have any merit, and additional samples must be taken as exploration proceeds. The only exceptions are the rare instances where abundant valuable minerals are exposed, such as a vein containing a great deal of visible gold, or a vein containing massive pitchblende. Thorough sampling is a complicated procedure usually done or supervised by an engineer or geologist, who decides on the best method for the type of deposit and other circumstances, and the number of samples necessary to provide a proper estimate of the average grade of the deposit or of ore shoots in the deposit.

The various methods of sampling and of estimating the grade of a deposit used by engineers and geologists need not be discussed fully, but a short description of sampling methods in general is given below, because some knowledge, even of the methods that are not applicable to prospecting, is desirable. Prospectors and members of the general public often read about samples in reports and news items, without understanding what is meant. The methods described below apply mainly to lode deposits, but some apply to placers. The types of samples with which prospectors should be almost exclusively concerned are chip, channel, and grab samples, but some prospectors may use light diamond drills, or may need to take a bulk sample. The general subject of prospectors samples is discussed later, after the descriptions of the various kinds of samples.

Channel Samples

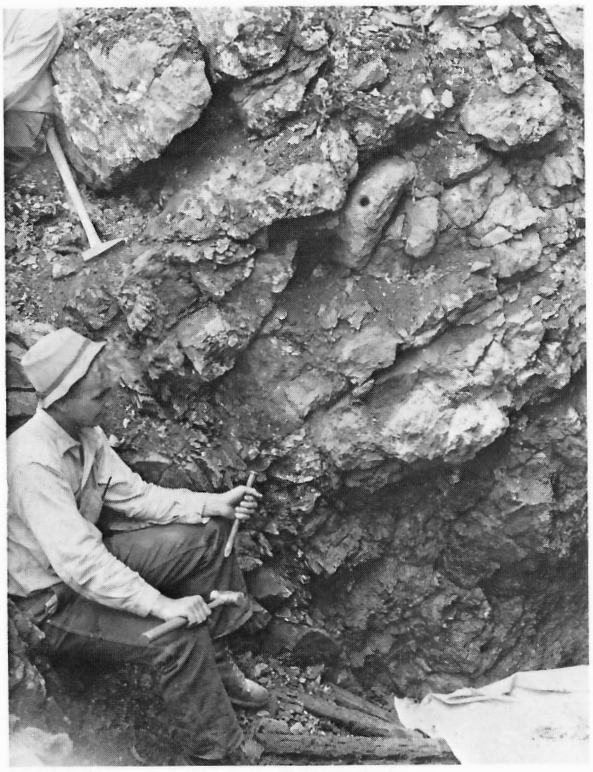
These are taken from a channel at least 2 to 4 inches wide and ¼ to 1 inch deep, cut at right angles to the strike of the deposit, usually with a moil and hammer, but a pick or bricklayer's hammer may be used instead, especially for fairly soft or brittle material. The surface should first be cleaned with a broom or brush. There is no definite rule as to the size of channel or the amount of material removed, as long as these are kept as nearly uniform as possible for any one sampling project. Larger channels are generally recommended when the minerals are distributed somewhat unevenly. If the valuable minerals are very spotty, channel sampling may not be practical. The sample should be as uniform and representative as possible, and care should be taken not to include more of the better or more easily obtained material. If a large piece is broken off accidently, it should be split and a piece of appropriate size used. Care must be taken to retain the more pulverized material, as some metalliferous minerals are reduced to dust during the cutting of the channel. The material cut from the channel may be caught on a sheet of canvas, plastic, or oilcloth, in a box, gold pan, or large can, or in a sample sack kept open with a wire loop. Great care must be taken to see that these are not contaminated by fine material from previous sampling. A pound or more is usually obtained for each linear foot of channel. If it is impractical to ship large numbers of samples, the individual samples may be carefully reduced in size, in the way explained in connection with bulk samples.



A. H. Lang 200890

Plate 71. Cleaning a rock-trench before sampling.

Plate 72



E. D. Kindle 83403

A. Sampling surface exposure with moil and hammer and canvas sheet used for catching the sample.



B. Channel-sampling with moil and hammer (underground). The channel has been outlined by chalk marks. Note that the channel is at right angles to the quartz vein, and that samples of wall-rock, as well as of the vein, are taken. Note also canvas sheet for catching the sample, and mask worn to prevent breathing rock dust (courtesy Hollinger Consolidated Gold Mines Ltd.).



A. H. Lang

C. Prospecting pick for chip-sampling. The sample may be caught in different ways; here a piece of semi-flexible wire inserted in the seam of a sample bag keeps it open, is bent to keep it flat against the outcrop, and serves as a handle.



A. H. Lang

D. Army entrenching tool used to expose outcrop. The blade can be adjusted to form a shovel.

It is useful to outline with crayon the places to be channelled. If the deposit contains bands of different material, they should be sampled separately. If it is fairly uniform, a length of not more than 4 feet of channel should be regarded as one sample; separate samples should be taken if a deposit is more than 4 feet wide. A few inches of the wall-rock at each side of the deposit should be sampled separately in case it also contains valuable minerals. If a deposit is less than 3 feet wide, separate samples of wall-rock should be taken for lengths sufficient to make a total of 3 feet. This is done because mine openings would have to be at least 3 feet wide, even if the deposit is narrower. Distances should be measured in tenths of a foot rather than inches, for ease in calculation.

Separate channel samples are usually taken at even intervals of 5, 10, or 20 feet, depending on the size of the deposit, the regularity of mineral distribution, and the time and money to be spent on sampling. If trenches or other exposures do not permit evenly spaced sampling, the channels are placed to suit circumstances, and this is taken into consideration when calculating the results.

Chip Samples

These are similar to channel samples, except that instead of cutting a channel, chips are knocked off at intervals of an inch or a few inches. A moil or pick is used, as in channel sampling. If a large piece is broken, it is split and an average piece is put with the sample. This is a cheaper and quicker method than channelling, and it is often sufficient, particularly for preliminary sampling, when it is seldom worth while to take careful channel samples from weathered or oxidized exposures. All the other matters referred to under 'channel sampling' apply to chip sampling as well.

Panel Samples

Panel samples are taken in the same ways as channel or chip samples, but from an area larger than a strip. They may be taken from areas a foot or several feet square, in an attempt to obtain a more representative sample. Lines may be laid out in the form of a grid, and alternate squares may then be sampled.

Grab Samples

Grab samples, sometimes called character samples, are pieces that are more or less representative of a deposit, taken at random from the deposit in place, or from a dump or mine car. If several such samples are taken with reasonable care to obtain average material, they may provide fair samples of deposits whose minerals are distributed fairly evenly, particularly in preliminary samples, but as a rule channel or chip samples are much preferable. In many instances what are said to be grab samples are really selected samples.

Selected Samples

Selected, or 'picked', samples are not really samples at all, because they are not representative of any sizable part of a deposit. They are specimens or small chips of the best parts of a deposit, and assays from them are of little use. Selected samples are desirable for purposes of mineral identification, because they provide better material with which to work. Also, a selected sample may be useful in the case of a deposit that appears to be of low grade; if such a sample gives only a low assay, it can be confidently assumed that the deposit is of still lower grade. Otherwise, selected samples should be avoided, yet many assay reports based on such samples are presented, either because the sampler had little knowledge of prospecting or mining, or in an attempt to attract attention. This has been done so often that the informed public discounts sampling reports that do not state the method of sampling and the width that the sample represents, and all high assays said to be from grab samples.

Bulk Samples

As their name implies, bulk samples are substantial amounts of a deposit, taken as representatively as possible. They range from a few hundred pounds to several tons in weight, and may be blasted from pits or trenches at the surface, or from underground workings. They are warranted only after a deposit of fair size and grade has been outlined, and are rarely needed by prospectors. They are taken for one of two purposes, or a combination of the two. One is to provide a more representative estimate of the grade of an unevenly mineralized deposit than can be obtained by averaging the results of several smaller samples. The other is to provide sufficient material for laboratory tests to determine whether the deposit can be treated economically and to learn the best method of treatment and the percentage of recovery that can be expected. If material is taken from more than one trench or underground location each sample is usually kept separate for assaying purposes, as this permits comparison of the grades of different parts of the deposit. Later, the samples may be combined for treatment tests. If transportation is not a serious problem, best results are obtained by shipping the entire sample or samples. Otherwise, the amount can be reduced in such a way that a smaller quantity is fairly representative of the entire sample. This can be done by shovelling the whole sample into a cone-shaped pile, perhaps after breaking the larger pieces with a hammer. Each shovelful is placed on the peak of the pile, so that small pieces roll down in a more or less even manner. When all is in place, the top of the pile is flattened by spreading the material as evenly as possible into a pile whose height is about one-tenth its diameter. Then two opposite quarters of the pile are shovelled into a new pile and it is quartered in the same way. This process is repeated until a sample of convenient size is obtained. It is best if the piles can be placed on a canvas or wooden floor, to prevent loss of the 'fines'. For very large samples, a portable crusher is sometimes used to reduce the pieces to fairly small size, after which the sample is reduced to a suitable size by coning and quartering, as described above, or by using a special sample-splitting device that gives more accurate results.

Muck Samples

'Muck' is the name popularly applied to rock or ore broken from a pit, trench, or underground working. While it is being shovelled out, a portion may be set aside to con-

stitute a sample. Fractions commonly used are one shovelful in every five, ten, or twenty. In much the same way, 'car samples' are taken from a car of muck or ore, sometimes by setting aside pieces taken at random as the car is being loaded, or placing in separate boxes material similar to that at the bottom, middle, and top of the load.

Dump Samples

When properties are examined after exploration or mining has been done, the dumps at trenches or from underground workings may be sampled in one of several ways. Small dumps may be coned and quartered, or a number of grab samples may be taken. Large dumps are commonly sampled by excavating pits or trenches in them at systematic intervals. If dumps have been exposed for a long time to rain and melting snow, some of the content may have been lost by the washing away of 'fines' or by solution.

Borings

Various methods of boring, which are explained later, may be used to obtain samples, usually at carefully spaced intervals. Drive pipes or post-hole augers may be used for testing placers or other soft deposits that are not too deep and where large boulders do not interfere. Another method that is sometimes desirable is to drill holes with hand steel or pneumatic drills, and collect the cuttings, either as a mud called sludge or as a dry powder. Larger holes are often put down with churn drills, the cuttings being pumped out and collected. Because churn drilling can only be done vertically, this method is generally used only for flat-lying or very large deposits such as placers and some iron deposits. Diamond drilling is widely used as a means of exploration and sampling. This method permits drilling in any direction and it provides a core that can be studied and sampled readily. Except in the case of core of very small diameter, cores that warrant assaying are usually split longitudinally with a special tool, one half being assayed and the other kept for further study should that be desired. In addition, the drilling sludge for separate intervals is often collected and assayed. Sludge samples are particularly useful for sections where core cannot be recovered, as sometimes happens when the rock is too soft, friable, or fractured. In some instances, sludge samples may be taken at first and discontinued if core recovery is good.

Composite Samples

After parts of samples have been used for assaying, the unused parts are sometimes lumped together to form a composite sample that may be assayed as a check on the individual results or used for treatment tests.

Prospectors' Samples

Many of the techniques described above are not applicable to the sampling done by a prospector when he first makes a discovery or when he does preliminary exploration. He might take chip or grab samples at first, choosing them so as to be as representative as possible. Later, if the deposit seemed to warrant it, he might take channel or muck samples. The utmost refinements are not necessary in the early stages, because the interest is in the possibilities of the deposit, rather than in careful calculations of tonnage and grade. The early sampling should, however, be done reasonably carefully and systematically. Deposits having valuable minerals distributed irregularly require a greater number of samples, and the samples themselves should be larger than for a uniform deposit.

The question of whether it is worth while sampling altered material at the surface of a deposit always presents a problem. Such material may give too high or too low results, or the assays may be almost the same as those obtained later from unaltered material. Often, nothing but partly altered material can be obtained during early exploration, and this has to suffice. If the deposit seems to be of fair size and if the geological conditions are favourable, further work is often warranted so long as the assays show reasonable content, even if the samples cannot be relied on completely because of near-surface alteration or of imperfect sampling.

A rough idea of the content of samples can at times be obtained on the spot by panning, or, in the case of radioactive samples, by testing them with a field radioactivity detector. Accurate results can be obtained only by sending samples to a laboratory for fire assay, chemical or spectrographic analysis, or special tests. The most reliable results are obtained if the entire sample is sent, but if this is not practical samples may be reduced before shipment. The method of quartering large samples has already been described. Smaller samples can be reduced in the same way, preferably by crushing them fairly fine, then placing the sample on a cloth or paper sheet, and mixing it thoroughly during successive stages of coning and quartering.

Samples should preferably be placed in small canvas bags specially made for the purpose. The bags should either be new, or be freshly laundered after being turned inside out, to avoid contamination by previous samples. If such bags are not available, any clean, strong, tight container will serve. Sample numbers should be written on a slip of stout paper which is rolled up to prevent the number from being obliterated, and is then placed in the container; alternatively, the number may be placed on an attached tag or on the outside of the container, preferably by some means that will not be affected by water. Careful notes on samples should be recorded in a notebook or on a map or sketch.

Except where provincial and territorial government agencies provide assays, prospectors requiring assays or analyses, or tests of bulk samples, should apply to one of the commercial concerns doing such work. Several firms advertise regularly in the mining press, and the prospector must decide for himself where to have the work done. It is not permissible for government agencies or employees to recommend any particular firm.

If in doubt, the prospector may send a sample to an assayer and ask to have the powdered sample or 'pulp' returned. This can then be carefully divided into two or three parts, which may be sent to other assayers. It is unlikely that the results will correspond precisely, because there may be slight variations in the samples, because analytical methods are accurate within certain accepted tolerances

only, and because different methods may give slightly different results. If, however, one set of results differs markedly from the others, a further check is probably called for.

The reports on assays and analyses frequently list minute quantities of metals or other elements present, but such components should not usually be regarded as valuable constituents of the deposit, as they are seldom economically recoverable.

Surveys and Sketches

Prospectors should be able to make rough surveys and to record the information on air photographs, tracings, or sketches. This information is valuable as a record of geological observations, mineral discoveries, locations of samples and specimens, and geographical features. These do not need to be surveyed or plotted with professional precision, but they should be shown with reasonable accuracy, and this can be done fairly simply and quickly after a little practice. The results are useful to the prospector himself in providing a record, and often by indicating trends that he might otherwise overlook. They are also invaluable when reporting or when trying to interest a possible buyer or backer. The kinds of surveys and mapping that a prospector might do fall into two classes. The first covers a fairly large area, such as a region being prospected, or a large group of claims. The second covers a smaller area such as a single claim, or part of a claim where a deposit has been found or where trenching has been done.

Large Areas

As mentioned elsewhere, one of the best ways of recording information is on an air photograph or on a tracing therefrom. Another method, if suitable maps are available, is to mark points and make notes on a copy of the map or on a tracing made from it. The positions of some points can be estimated sufficiently closely by eye. Others can be fixed by taking bearings, pacing distances, or taking altitudes with a barometer. These methods are discussed later.

In areas where timber is too thick to permit fixing positions by eye or by taking bearings to known points, and in detailed prospecting of a group of claims or a particularly favourable area, it is often desirable to prospect along parallel lines at intervals of 100 to 500 feet. To do this it is usual to mark off the intervals on a base line, which may be the side of a claim or a special line selected for the purpose. The prospecting lines are run at intervals from the base line, and are usually arranged to cross the general trend or formations or structures. They may be kept straight by taking repeated sights with a compass, or after being begun by compass, they may be run as 'picket lines'. To make a picket line, a picket is placed at the starting point and another by taking a compass bearing from the starting point. Then, if two men are available, one man may sight along the two pickets and wave the second man into position for the third picket, and so on. If a man is working alone, he can move sideways until he is in line with the pickets already in place, and then set another. Pickets are usually at even intervals, such as 100 feet, so that observations can be referred to these fixed points, but if this is not necessary the pickets may be at any convenient distance generally on high points to permit visibility. After the lines have been run they may be plotted on plain or graph paper, to make a plan on which observations can be recorded. Such a plan is illustrated on Figure 19. As well as aiding in ordinary detailed prospecting, such lines may be used for the recording and plotting of geological, radioactivity, or dip-needle surveys.

Smaller Areas

For smaller areas such as might embrace a mineral deposit or a group of trenches, a plan on a larger scale is desirable. Suitable scales range from 1 inch to 10 feet to 1 inch to 100 feet, according to circumstances.

If the points to be located are fairly close to one another, say within 1,000 feet, a base line may be run in a convenient place, as illustrated on Figure 19. The points to be located may then be measured by 'offsets' at right angles to the base line. The direction of the offsets can usually be determined with sufficient accuracy by eye, but if the distance is great a bearing can be taken from the point to the base line. If two 50-foot or 100-foot tapes are available, it is convenient to lay one along the part of the base line being used at the time, and to employ the other for measuring offsets. If only one is available, the offsets can be measured first, the points where they intersect the base line may be marked, and the positions along the base line may then be measured. For rougher surveys, pacing is sufficient.

If the distances are too great, or if timber is too large and too thick to make a base line practical, points may be located by making a 'traverse' composed of several bearings and distances, from a point of origin such as a corner of a claim. If a traverse consists of only two or three courses (bearing and distances) these can be plotted merely by using a scale and protractor and assuming that the bearings were properly taken and not affected by local attraction. For more accurate results, particularly if a traverse consists of three or more courses, it is better to make a 'closed traverse' as illustrated on Figure 38. This is done as follows:

Suppose that the first point to be located was a vein exposed in an outcrop at point C. The nearest point of ref-

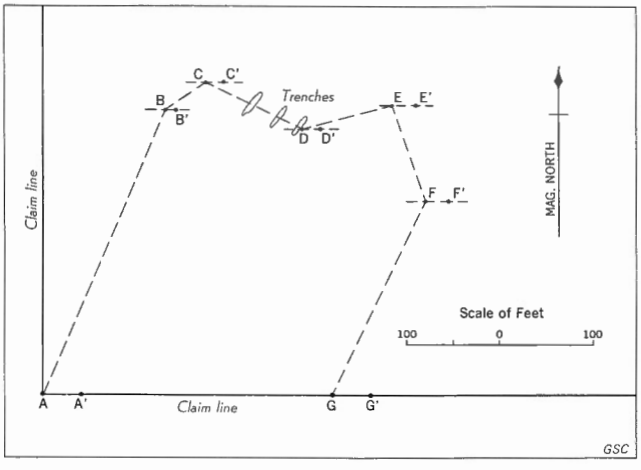


Figure 38. A closed traverse and a method of adjusting it.

erence was the claim corner, A, from which a bearing was taken in the general direction of point C. The prospector measured along the line of this bearing, and when he reached B, from where he could see the outcrop C, he took another bearing, B to C, and measured this distance. From C he took course C-D, to cross three trenches whose distances from C were measured. From the trench at D, he took course D-E to another outcrop, then E-F to the last point he wished to locate. He then took course F-G to strike the claim line, and finally a course down the line to close the traverse at A. The courses were then plotted on paper, to a convenient scale, using a protractor and measuring scale. Any point was taken to represent A, and a side of the paper was taken to represent a north and south direction. When such a closed traverse is plotted, it would be most unlikely that the last course would end exactly at the point of origin, A. It is more likely to end at another point illustrated by A^1. If it is badly out of closure, there must either have been one or more serious errors in bearing or distance, or a serious magnetic disturbance at some point. If the traverse is re-run, an error will probably be detected, permitting reasonable closure. If the closure is only slightly out, a line is drawn between points A and A^1, and short parallel lines are drawn through the other points of the traverse, along which the other points are adjusted proportionately as shown on Figure 38. The letters with the strokes after them represent the first positions, and the others the adjusted positions. A special method of measuring the amount of adjustment is used by surveyors, etc., but for rough purposes the adjustments can be estimated by eye. After adjustment the sketch may be used as a skeleton around which details such as lakes, streams, outcrops, contacts, sampling positions, etc., are sketched. Usually, the more important details are fixed to the traverse by measured offsets, and the remainder are drawn by eye.

Fixing Positions

Positions are located by bearings, distances, or elevations above sea level or by combinations of these.

For simple surveys, bearings are usually taken with a compass, in which case it is necessary to consider the possibility of local attraction, and perhaps to consider the declination. The compass does not point to the true or astronomic north, but to the magnetic pole. The angle between true and magnetic north, called the declination, varies from district to district and is noted on the legends of most maps. A special map showing declinations for all parts of Canada is published by the Observatories Branch, available from the Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa. The declination can also be learned by sighting along a surveyed line whose true bearing is known, and noting the difference between this bearing and the compass reading. Local attraction may be caused by metal objects carried by the observer or lying nearby, or by magnetic minerals in nearby rocks. It can usually be avoided by holding the compass well away from belt-buckles, knives, hammers, rock outcrops, etc., but at a few places magnetic outcrops may cause confusion.

If bearings can be taken to two points shown on a map, the position of the observer can be located by plotting on the map the reverse bearings from the known points, whereupon the intersection will fix the observer's point. The points of reference must not be too close together, or too nearly in line with one another.

Distances can be measured by pacing, using 2½ feet as an average pace, or by means of a tape measure. 'Metallic' tapes made of treated cloth in lengths of 50 or 100 feet are most practical. Some prospectors use a measured length of heavy cord, such as trolling line or cod line; these stretch, but are good enough for approximate surveys. A 6-foot steel tape is useful for measuring short distances, such as the widths across which samples are taken.

In mountainous country a small aneroid barometer is useful for locating positions on contoured maps, because distances measured by pacing or other means are not useful in locating points on steep slopes. A bearing to a known point, together with a barometer reading, generally gives a fairly accurate location. Because a barometer is influenced by change in weather, its reading should be noted frequently at points where elevations are shown on a map; then when a reading is taken on a point to be fixed, an adjustment can be made on the assumption that the weather has not changed much since the last check-reading was taken.

Plotting

Traverses and sketches can be plotted on ordinary paper. However, graph paper, or tracing paper laid over graph paper, is convenient, because right-angled lines do not then need to be plotted, and because the divisions on the paper can be used instead of measuring with a rule or scale. Bearings can be plotted with a protractor. Special rules can be obtained for different scales of plotting, but these are not essential, because the distance can be estimated from whatever divisions the rule available happens to have. For example, if the scale is 1 inch to 50 feet; ½ inch is 25 feet; and ¼ inch is 12½ feet, which is almost the same as 10 feet. Simple rules and protractors that are suitable can be bought in chain stores, rules divided in tenths of an inch rather than eighths being preferable. A sharp pencil should be used for plotting and sketching, and it should be of moderate hardness, such as F, or H, to prevent smudging and frequent sharpening.

To decide on a suitable scale for a sketch, consider the size of the area to be illustrated and compare this with a piece of paper of convenient size. Thus if it is to be a general sketch of an area about a mile square, and the paper is 6 inches wide, a good scale would be 1,000 feet to 1 inch, because a mile would be represented by a little more than 5 inches, and even thousands of feet would be easy to measure. For sketches illustrating showings or trenches within a shorter distance, scales might be 1 inch to 100 feet or even 1 inch to 10 feet.

Prospectors' Reports

A prospector generally has to make a short report and one or more sketches on a discovery that he thinks attractive. This may be because he is employed by a company or

syndicate that requires him to do so, or because he has to report to one or more backers or hopes to interest a company in buying his property or financing further work, or because he has to report a discovery or the results of exploration to a government agency, as in the case of uranium discoveries. If a prospector is employed by a company the kind of reporting may be specified; if not, the following guides may be useful.

A prospector's report need not be long or written in highly technical language, but it should give essential information in as clear and neat a manner as possible, because these matters affect a reader's reaction. The following outline, or parts of it, may be followed to prevent overlooking some important consideration and because the sequence is logical. It should be remembered that the prospector should not count on being able to provide vital parts of his information orally because the report may be filed or passed on, and thus read by others when he is absent.

Title of Report

State the name of the discovery or claim group, the province or territory, and the name of the writer.

Location

State the number of claims concerned (if staked), describe the location and means of reaching the discovery or property, including all important details such as how to get in touch with a guide, and recommended boat or air service, if applicable. The report should be accompanied by a regional map or tracing showing the location, and also by another more detailed map, tracing, sketch or air photograph showing with reasonable accuracy the position of claim boundaries, discoveries, trails, geological observations, sampling positions and numbers, buildings, camps, and so forth. From a properly prepared report and its accompanying maps, etc., it should be possible for an engineer or geologist to reach the property and find the showings without a guide.

Ownership and History

Give the name of the discoverer or owner, together with any pertinent information such as ownership of surface or mineral rights, data of staking, assessment work done or recorded, etc.

State the date and manner of discovery. If all or some of the discoveries were made by others at some previous time, a note of the earlier history should be included. If the ground was staked previously by others, the date and previous ownership should be mentioned, and if systematic prospecting or any exploration was done by previous owners or others, as much as is known regarding the character of such work and the availability of records or drill cores should be stated.

General Information

Give a short account of the topography, amount and kind of timber, local labour supply, power supply (if available), length of summer season, and any other matters that might affect an exploration or mining program. If important mines or interesting prospects occur in the district, they should be mentioned and their distances, similarities, or differences to the property being described should be outlined.

General Geology

Describe the main features of the local geology as well as of the claim group or the immediate vicinity of an unstaked discovery. This may be taken from geological reports and maps, or described from personal observations if reports and maps are not available. A copy of a published geological map, or a tracing of part of one, on which showings are added may be included. The reference number of a report or map should be given.

Description of Discoveries

State the number of separate deposits apparently present; their type such as pegmatite or quartz vein or shear zone, as accurately as possible; the lengths and widths for which the deposits have been traced, giving the distances between exposures (for example, one vein has been traced for a total distance of 250 feet, by means of three outcrops and four trenches which are from 10 to 40 feet apart, and in these exposures the vein varies in width from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet). State the number of strippings, pits, or trenches, and specify which pits or trenches are in overburden without reaching bedrock, in overburden to the rock surface but with no deposit visible, in overburden to the surface of the deposit, or blasted into the deposit. The depths to bedrock or into the deposit should be given. In some cases there might be diamond drill holes to describe.

The locations of specimens or samples, either submitted with the report, or tested previously, should be described, or mention should be made that they are noted on an accompanying map, etc. The type of samples and the widths across which they were taken should be stated. Assay reports should be attached, or, if the information is quoted, care should be taken to see that the figures are correctly copied and that the name of the assaying firm is included.

In describing distances, care should be taken to avoid exaggeration, because experienced mining men quickly detect it. Misleading statements are often made quite sincerely by inexperienced prospectors. For example, they may find a few small exposures of quartz or pegmatite, which represent only small veins or dykes scattered over a considerable distance, and may then state that the deposit is 100 feet wide and 2 miles long.

Closing

Sign the report, giving the date, permanent address, and, if advisable, temporary address. If the writer is unknown to the person to whom the report is going, it would be well to state experience and qualifications.

ADVANCED TESTING

If preliminary examination by a mining engineer, geologist, or experienced prospector indicates that further work is warranted, this may take the form of additional removal of overburden, rock trenching, boring, or underground exploration. Such work is usually beyond either the means or

the ability of prospectors. It is usually laid out by an engineer or geologist, who reappraises the results from time to time and either recommends that another step be taken, or that work be stopped because the results are unfavourable. The prospector may be engaged to do some of the work under supervision, or he may have to do some further exploration himself, as assessment work, if he cannot dispose of his discovery and thinks it is worth holding. However, advanced work is usually done by experienced men hired by a company, or by a contractor who has the experience, staff, and equipment for surface work, boring, shaft-sinking, or tunnelling. A short account of the subject is given in the following paragraphs, because prospectors and those who finance them should have a general knowledge of such matters.

In most instances, testing if carried through all stages consists first of surface work, then of diamond drilling, and finally of openings driven from an adit or shaft to confirm the results of drilling. This is not always so, however. A deposit may be so well exposed at the surface that no removal of overburden is necessary. Or, if the geological environment, size, and exposed minerals are sufficiently attractive, the engineer or geologist may decide that little or no pitting or trenching into the surface of the deposit is necessary, and instead may recommend that drilling be begun at once. In rare instances, a prospect adit or shaft may be recommended without preliminary borings, particularly in the case of a deposit that seems so irregular that borings would not give suitable information. In the early days, particularly in the Cordilleran region, prospectors were prone to drive adits and sink shafts, alone or with a partner, on meagre showings. Sometimes a man would work for wages until he had saved enough to finance another spell at his 'mine', and this was repeated year after year. Occasionally the objective warranted such devotion, but often it was little more than a dream that grew into a conviction as the prospector continued his long and lonely task. Today, better organization of the mining industry has led to a distinction between prospecting and testing of prospects, and prospectors are normally not expected to do more than preliminary work on their discoveries.

Although it is generally desirable for companies to confirm results of borings by making underground excavations, some deposits are sufficiently regular and their valuable minerals are sufficiently evenly distributed to permit acceptable calculations of tonnage and tenor based on the results of borings alone. On the other hand, some deposits are so erratic in extent and in mineral distribution that diamond drilling may not be recommended. In such cases, if the surface showings are promising, an exploration adit or shaft may be driven immediately after the completion of surface exploration.

Removal of Overburden

If advanced exploration requires the removal of overburden to trace a deposit and permit inspection or sampling, the most usual way is to employ labourers to dig pits or trenches at designated places. Years ago, such excavations were carried to considerable depths by shovelling onto successive benches or by using a windlass and bucket. With the availability of other methods of exploration, pits or trenches are now rarely excavated deeper than 4 or 5 feet. When trenching in frozen ground, it may be necessary to work in stages to permit natural thawing, or to hasten thawing by using fires, warm water, or steam from a boiler, or by using a ground sluice.

Bulldozers and ditch-digging machines are now often used to remove large areas of overburden or to dig large trenches across deposits, in districts where it is feasible to do so and when it is desirable to remove considerable overburden. Water under pressure may be used to clean the rock after bulldozing has been done, or even to remove large areas of overburden.

Rock Trenching

Under certain circumstances considerable trenching into the deposit itself may be desirable to study and sample



S. C. Robinson 142107

Plate 73. Using a portable percussion drill with self-contained motor for drilling blast-holes for rock trenching.

relatively unaltered material. Such work requires the drilling of *blast-holes*. Although this may be done by hand drilling, in most instances today any drilling beyond that carried out by a prospector at an early stage of exploration is done by portable percussion drills powered either by a self-contained gasoline motor or by a movable air compressor. In addition to trenches, test pits may be sunk in rock to depths of 10 to 50 feet, to determine the dip of a deposit and the amount of minerals present at these depths. Today, however, diamond drilling has become so efficient and manual labour so expensive that the tendency is to rely less on surface trenching or pitting, and to proceed with borings if a deposit seems at all promising. In most cases, however, enough surface work, particularly removal of overburden rather than rock trenching, should be done to make sure that diamond drilling is warranted and suitably carried out.

Borings

Borings (drill-holes) by various methods are often used to provide cuttings or cores of overburden or rock for study and assay. The principal method is diamond drilling, because it can be done in any direction and provides cores for thorough examination. Its use during the last fifty years or so has revolutionized the testing of prospects and permitted the evaluation of anomalies, and much of the increase in Canadian mineral production is attributable to improvements in techniques and equipment by drillers and manufacturers in this country. However, other kinds of drilling, mainly churn and special rotary, are done extensively.

Diamond Drilling

The diamond drill was first used in 1864 for drilling blast holes in a railway tunnel in the Alps. The method was quickly adapted for obtaining cores in connection with mining exploration. The first use in Canada was in 1871, for exploring a coal deposit in Nova Scotia, and in the following year diamond drilling was done at the Silver Islet lode mine in Ontario. Equipment and techniques improved gradually, and diamond drilling became widely used in many parts of the world, revolutionizing mineral exploration. In Canada today, many large mining companies each own several diamond drills that are used for exploration, for drilling long blast holes, and sometimes for drilling holes for cementing off strong flows of underground water. Most diamond drilling in Canada, however, is done under contract by large drilling companies. A few years ago the total amount of diamond drilling done in Canada was estimated to be one thousand miles a year.

The principal parts of a diamond drill are the bit, reaming shell, core barrel, drill rods, and power unit. The bit is a ring-shaped piece of metal in which diamonds or fragments of diamonds are set to form a cutting tool (*see* Pl. 74). Early bits contained a few, fairly large commercial diamonds, whereas modern bits usually contain many small ones. Above the bit is placed a cylindrical reaming shell, also containing diamonds, which trims the hole to a constant size. As the bit is rotated the core of rock passes upward through the centre of the bit and shell, and enters



Plate 74. Diamond drill bits of various sizes (courtesy J. K. Smit & Sons Ltd.).

a tube called the core barrel. The barrel is attached to a threaded hollow steel drill rod which is rotated by the power unit. For use in drilling from the surface, the core barrel and drill rods are usually 10 feet long, and for drilling from underground workings they are generally 5 feet long. When 10 or 5 feet of core has been drilled, as the case may be, the apparatus is withdrawn from the hole, the core is removed, and an additional length of drill rod is screwed on. This operation is repeated until the desired length has been drilled. A 'wire-line' core barrel, that permits removal of core without removing the drill rods from the hole, has been developed for use in connection with BX hole ($1\frac{5}{8}$ inch diameter), and experiments are being carried on in connection with other barrel sizes. The lengths drilled range from very short holes drilled under surface showings mainly as a means of sampling, to ones several thousand feet long, but most are between 100 and 1,000 feet. At first, drilling from the surface was usually powered by portable steam engines, but these have been almost entirely superseded by gasoline engines (*see* Pl. 75). Drilling from underground workings is usually powered by compressed-air motors because of the danger of fumes from internal-combustion engines. Pressure is applied to the drill by a screw actuated by the motor, or by a hydraulic system. When short holes are drilled from the surface, with light equipment, the rods are usually pulled out by hand, but for standard operations a tripod is erected to carry a pulley and cable, the cable being wound on a power winch attached to the drill motor. A separate motor is almost always used to power a pump, which circulates water down the hollow drill rods, to cool the bit, and to flush out its cuttings, but 'dry drilling' in places where water is scarce has recently been reported to have been successful. The drill and other equipment are usually skidded into place and moved from hole to hole by a light tractor or a winch.

Formerly the most commonly used core diameters were $\frac{7}{8}$ inch (EX) and $1\frac{3}{16}$ inches (AX). Recently larger diameters of $2\frac{9}{32}$ inch (EXT) and $1\frac{9}{32}$ inches (AXT)



D. F. Kidd 76114

Plate 75. A diamond drill beginning an inclined hole, before the erection of tripod used for hoisting out the drill rods.

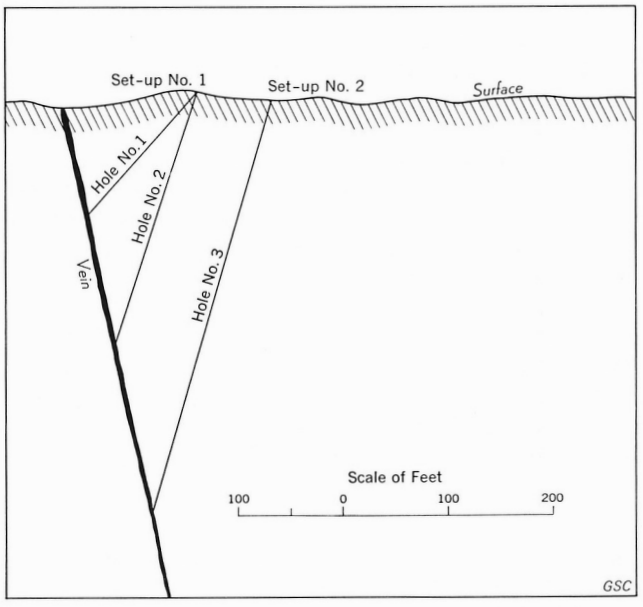


Figure 39. A common arrangement of diamond-drill holes.

have come into use. AX or AXT core is favoured under certain conditions to provide a larger sample or in an attempt to obtain better recovery of core. Some authorities advise beginning with this size, and if good recovery is obtained, switching to EXT if satisfactory results are attained, because the smaller size is a little cheaper. Cores larger than AXT are used in special circumstances. An asbestos deposit was bulk-sampled by 12-inch coring.

Light drills weighing about 200 pounds are available for drilling short holes in places where transportation is difficult, and for use by independent prospectors. They usually produce core $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in diameter, which is called 'x-ray' core although it has nothing to do with X-rays. These drills can be modified to produce EX or EXT core, which is said to result in better core recovery. Other types of light diamond drills that can be dismantled for back-packing and are somewhat like an outboard motor are available.

One of the problems of diamond drilling is in obtaining good core from fractured, soft, or brittle rock or ore. This is particularly true when drilling through zones containing abundant metalliferous minerals, for which the best recovery of core is desired. A main cause of poor recovery is too rapid drilling, but there are others. Experienced drillers and reliable contractors are the best assurances of satisfactory results.

Diamond drilling is usually done at even intervals of 100 to 500 feet along the strike of a deposit, favourable stratum, or favourable structure. Later, if encouraging results have been obtained, intervening holes are usually drilled to provide more thorough information. The final spacing depends on the irregularity of the deposit and the amount of accuracy desired, holes sometimes being spaced as closely as 25 feet to obtain detailed information. To intersect a zone at two different depths without having to move the drilling rig, a common practice is to incline the holes at two different angles, as illustrated on Figure 39. Then, if another deeper hole is desired, the rig is 'stepped back' to a second position on a line perpendicular to the zone or vein and passing through the first 'set-up'. In large drilling programs it is desirable to space holes so that they will coincide with the direction and position of co-ordinate and section lines that would be used if underground operations are undertaken later.

Typical diamond drilling is not usually done by prospectors because it is a fairly expensive form of advanced testing. A drilling project is almost always planned and supervised by an engineer or geologist because location of drillholes and the study and sampling of core are highly technical matters. Some experienced prospectors do, however, successfully use light diamond drills for early testing of discoveries or for assessment work.

The cost of diamond drilling varies with location, kind of rock, amount and kind of overburden, size of core, number and length of holes, availability of water, and other factors. It is generally a few dollars a foot. Drilling from underground workings is considerably cheaper than drilling from the surface, because the equipment can be moved on the mine tracks, and because water and compressed air services are already installed. A contract for drilling several holes would generally be more favourable than for one or two because of the initial cost of transporting and caring for men and equipment.

Diamond drill cores should be carefully studied and recorded, and securely stored in a dry place. Special boxes and strong racks should be used, and boxes should be clearly marked with the hole number and footage. Good permanent markings are made by stamping or inscribing numbers on a metal tag and nailing this to the end of the box.

Other Types of Boring

Various kinds of drills such as spring-pole, shot, and Empire have been used but, other than diamond drills, mainly churn and rotary overburden drills are now used.

Churn drills similar to those used for drilling wells for water are also used for exploring some kinds of mineral deposits. The hole is dug by a bit attached to a cable, which may be jerked up by a spring pole, but more usually is pulled by a motor-driven wheel; the bit drops down the hole to strike a series of chopping blows on the rock at the bottom. Water is circulated in the hole to flush up the cuttings. Particles from upper parts of the hole may drop down and contaminate the sample, particularly when drilling soft deposits such as placers. To prevent this, casing pipe is driven down the hole, the bottom of the casing being kept as close as possible to the bottom of the hole. In Canada, churn drilling is done mainly for testing placers, and when many vertical holes are required to test lode deposits. An example of the latter use is the drilling done at some of the iron deposits in the Labrador Trough.

A special type of rotary drill with a large bit shaped somewhat like an auger has recently been used successfully for obtaining soil samples in geochemical prospecting done to supplement geophysical anomalies. They are sometimes used to obtain samples of the upper part of bedrock as well.

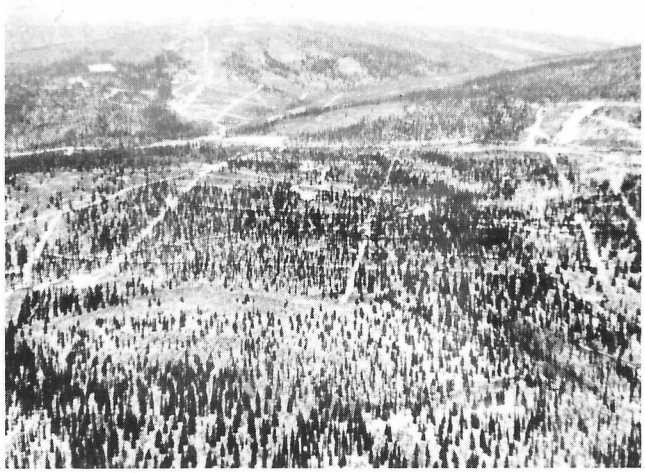


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Plate 76. A drilling project in Yukon Territory. Roads for moving drills are indicated by light snow (courtesy A. Aho).

Underground Testing

Although rock trenching and most borings are, in a sense, underground testing, this expression always means the sinking of shafts or the driving of horizontal openings to explore a deposit. Some of the terms used to describe such openings require explanation. To the layman, any horizontal opening is a tunnel. Strictly speaking, however, a tunnel is open at both ends, like a railway tunnel. One that is driven into a hillside and open at one end only, as is usual in mining, is properly called an *adit*. Horizontal openings driven from an adit or a shaft are given the group name of *laterals*, but are further designated as *drifts* if they follow along a vein or other deposit, and *cross-cuts* if they are driven to probe a deposit at right-angles to its strike. An opening driven upward from an adit or lateral is called a *raise*, and one driven downward is called a *winze*.

Before diamond drilling became as usual a method of testing as it is today, exploration shafts and adits were more common during initial stages than they are now. They were often driven with hand steel, and many were just wide enough for a man to work in or crawl through. Blasted rock was taken out in buckets or wheelbarrows. Small openings of this kind are popularly called 'gopher holes' or 'coyote holes'; they are now almost a thing of the past, because machinery is cheaper than labour. Nowadays, if underground work is required, shafts are usually made fairly large and laterals are driven wide and high enough to permit use of air drills and mine cars.

After laterals have been driven, the surrounding rock may be explored by diamond drill from 'stations' along the lateral. This is commonly called underground diamond drilling. It is similar to diamond drilling from the surface except that the drilling rods used are only 5 feet long, for easier handling in confined spaces, and the drills are usually rotated by compressed-air motors.

Drilling and Blasting

Pitting and trenching into solid rock to reveal unweathered parts of a deposit are not done as commonly as formerly because of advances in diamond drilling; but they are necessary at times, and under some circumstances work of this kind is done by prospectors. It is now often carried out by use of portable power drills and detachable bits; the arts of drilling by hand and of sharpening drills are therefore required less than formerly, but as some prospectors may need to practice them, the following notes are included. It must be emphasized, however, that it is difficult to learn these skills merely by reading, and that practical instruction by experienced men is almost essential. In some provinces it is necessary to take tests in knowledge and proficiency in handling explosives and to obtain a Blaster's Certificate in order to use explosives. Such certificates are required in Alberta, British Columbia, Quebec, Yukon Territory, and Northwest Territories. In New Brunswick the Department of Labour conducts an annual Powderman's Trade School.

Equipment

The drills most commonly used for hand drilling are made of $\frac{3}{4}$-inch octagonal steel. They are prepared in sets of three or four, having lengths of about $1\frac{1}{2}$ to 4 feet. They are usually sharpened chisel fashion, but the edge may be slightly curved for drilling very hard rock. The width of the face on the longest drill in the set is slightly more than $\frac{7}{8}$ inch, which is the diameter of the sticks of explosive used in this work, and each succeeding bit in the set is $\frac{1}{16}$ to $\frac{1}{8}$ inch wider. The shortest drill, called the starter, is used first, and is widest to permit the next to be placed readily in the hole, and so on. Nowadays, drills having inserted tungsten-carbide cutting edges are popular because of their hardness. A 4-pound hammer, called a *single-jack* is commonly used when a man is drilling alone, and an 8-pound one with a long handle is used when one man holds the drill and the other strikes.

A *scraper* 3 to 4 feet long, pointed at one end with a small flange projecting at right angles from the other end, is made



A. H. Lang 82691

Plate 77. Drilling by hand at a pegmatite deposit, with two men striking and one man (seated) holding the drill. A longer drill, for use when the hole is deepened, stands in the pit.

from an iron rod ⅜ inch in diameter. This is used for removing cuttings from the hole.

The blasting explosive most commonly used is "60% Gelatin Dynamite". Appropriate blasting caps and fuse, fuse assemblies, and electric blasting caps may be purchased. It is essential that all explosives be stored in a cool dry place. Detonators and blasting caps must never be stored in the same building with dynamite. Government regulations controlling the handling and storage of explosives should be obtained, studied, and rigorously followed. The remainder of the equipment required for blasting comprises a wooden mallet and wedges for opening boxes of explosives, a pointed hardwood stick half an inch in diameter and 3 to 4 inches long, for making holes in sticks of explosive, a wooden tamping rod three-quarters of an inch in diameter and 6 inches longer than the longest drill hole, a pair of cap crimpers, and a sharp knife.

Drilling

The spacing of holes depends on the depth to be drilled and on the kind of rock and amount and angle of fracturing. It can be learned only from instruction or experience.

A hole is begun with the shortest drill, and the drill is rotated about 45 degrees after each stroke of the hammer. Goggles should be worn to prevent chips of steel from entering the eyes, and gloves to protect the hand or hands holding the drill. If the head of a drill is 'mushroomed' it should be smoothed by forging to prevent damage to the hands. Most holes drilled during surface exploration are directed downward, and in such holes the cuttings interfere with the drill unless they are kept in suspension by water poured into the hole as required. A small piece of sacking or similar material is kept around the drill at the top of the hole, to keep mud and water from being expelled when the drill is struck. If all the cuttings are not flushed out, the hole may be cleared with the scraper. As the hole is deepened, longer drills are used.

Blasting

The blasting that a prospector might have to undertake would probably be either drill-hole blasting or what is called bulldozing, mud-capping, or sandblasting. In blasting, the charge is detonated by means of a primer cartridge made up in the following manner. A piece of fuse, never shorter than three feet, is trimmed squarely across one end with a sharp knife, and that end is inserted gently and without twisting the full distance into a blasting cap. While it is held in that position, the upper part of the blasting cap is firmly fastened to the fuse by means of the crimper. A double crimp with the latest type of crimper will give a virtually water-tight joint, but under wet conditions a special water-proofing compound, soap, or cup-grease may be applied. The paper fold at one end of a stick of explosive is then carefully opened, and a hole 2½ to 3 inches deep is made in the end of the stick by means of the wooden tool described above; the fused cap is inserted in this hole, and the paper is then drawn closely around the fuse and tied tightly with string. This assembly of cap, fuse, and stick of explosive, is called a 'primer cartridge' or 'primer'. Great care must be taken to avoid kinking safety fuse, as this might result in a misfire. When several shots are to be fired in one blast the fuse for all primers should be cut to the same initial length, no matter what trimming is done after the holes are loaded.

Before loading, the holes are carefully cleaned out with the scraper and tested with the tamping rod to see that there is no obstruction. Usually the primer is loaded first; it must never be tamped but merely pushed to the bottom of the hole, care being taken to ensure that the cap is not pulled out. Sticks on top of the primer are tamped in firmly, but not pounded, and great care must be taken to avoid damaging or kinking the fuse. It is usually not good practice to load the hole for more than two-thirds of its length. The use of some stemming material such as clay in bags or even earth, old pieces of sacking, etc., pressed firmly into the collar of the hole on top of the explosive, will help considerably.

If a number of holes are to be fired (called a 'round' of holes) this is arranged so that the holes fire in a regular order. This is necessary for two reasons; first, the holes have usually been drilled so that it is necessary for one to break

a certain amount of ground in order to give the next an opportunity to break; second, so that a count can be kept of the number of shots. "Rotation Firing" is accomplished by trimming the various fuses to different lengths. After the holes have been loaded (with fuses of equal lengths) a piece is cut from the fuse in the hole to be fired first. The length cut off will depend on the number of holes in the round. This piece of fuse is used to adjust the length of fuse for the number two hole, which must be at least 2 inches longer. The number 3, number 4 holes, etc., are treated in a similar manner. When this has been done the ends of the fuses are split longitudinally for about half an inch with a sharp knife. The fuses are then lit in the order in which they are to go off.

Fuses are lit by three standard methods: the spitter, the hot-wire lighter, and the igniter cord and connector. The spitter is simply a length of fuse with notches in it, the notches being sufficiently deep to cut the powder train and spaced an inch to 2 inches apart. As the fire travels along the fuse, flame blows out of each notch in turn and this is used to ignite the fuses in the round. As the spitter burns, it keeps the blaster informed of the length of the first fuse that has burned, and so tells him the amount of time he has left to get to a safe place before the charge explodes. The use of matches, candles, miners' lamps, etc., to spit a round is an unsafe practice that should never be permitted, because the igniting fuse will as often as not extinguish the flame. The use of the hot-wire lighter is recommended: this is simply a piece of wire coated with a hot-burning compound that may be ignited by a match. The fuse is ignited by placing the burning part of the lighter in the split end of the fuse. The igniter cord is used as a positive means of igniting the fuse, special connectors being used to provide the communication between the end of the safety fuse and the igniter cord.

Too much emphasis cannot be placed on the importance of using fuses of a sufficient length. In most provinces a minimum of 3 feet is specified by law, and if more than one hole is to be blasted, a longer fuse must be used. The burning speed of the standard fuse is 40 seconds to the foot, so that 3 feet allows less than two minutes for lighting a round. The fuse manufacturers state that their product has an allowable variation of 10 per cent in burning speed and, for this reason, as liberal a trim as possible should be used; a good rule is to allow half an inch per foot of fuse.

Bulldozing, mud-capping, or sand-blasting is the method used when rocks are to be broken without drilling a hole. A place on the rock, preferably a small hollow, is selected and a charge, composed of three or four sticks and primer, is placed on the rock at this point. It is then covered with mud or clay and fired as in the case of a drilled hole. The effect of the blast is not nearly so great in bulldozing as it is with a drilled hole, but the factors of time and the expense of drilling sometimes justify the use of this method.

It should be unnecessary to state that every precaution must be taken to see that all approaches to the locality where blasting is being done are carefully guarded. Immediately the round or charges are lit warning must be given by shouting 'fire' several times. Drillers and others take cover until the 'all clear' is given.

No discussion of blasting or blasting methods is complete without speaking of the treatment of misfires. If the rules and precautions given above are adhered to, very little trouble should be experienced from this cause. However, if a misfire does occur, no one should be allowed to return to the scene of the blast until at least thirty minutes has elapsed. After that time the holes can be examined with comparative safety. If it is found that for some reason the charge has not exploded, no attempt should be made to remove the old charge; it should be fired by means of a fresh primer in the hole on top of it. Another precaution against misfires: never cut fuse until ready to use it.

Sharpening Drills

Several years ago it was customary for prospectors to sharpen their own drills, moils, and picks, but the decline in hand drilling, improvements in transportation, and development of tungsten carbide bits have almost made field blacksmithing a thing of the past. If prospectors need to drill by hand, they can nowadays often take with them a sufficient supply of sharpened drills and moils, send dulled ones to a blacksmith for sharpening, or carry a carborundum grinder for sharpening tungsten-carbide bits.

Assays and Other Tests

A general knowledge of the various tests that may be performed on samples is important for prospectors and others because the highly technical nature of the work and the terms used are confusing to inexperienced persons, and unnecessary expense may result from ordering unsuitable kinds of tests. The following description is not intended to teach the methods, because with one or two minor exceptions they are too technical and require too much equipment to be undertaken in a 'do-it-yourself' way. Only a brief explanation of the principal tests and their interpretation, and the ways of obtaining them is intended. The more technical parts can be ignored if desired. Reference is not made here to the simple tests mentioned in Chapter 3 and Appendix VI, which may be made on specimens for the purpose of mineral or elemental identification, but rather to tests for determining the presence or quantities of elements contained as major or minor constituents of samples.

It is impossible to determine every element that might be present in a sample to the extent of a few atoms, but extremely small quantities can be detected. Such amounts are of interest only for research and for geochemical prospecting, and are not recoverable commercially; reports mentioning them sometime mislead prospectors and the general public. It is also impossible to make absolutely correct analyses of the quantities present in samples, because minute amounts of the sample may be lost as dust, or in other ways, or because slight contaminations may be caused by dust or by the chemicals used, even when all possible precautions have been taken, and because slight imperfections may exist in the instruments used for weighing or

other purposes. Very close approximations can be made for research purposes when the time and cost are warranted, but in general less accurate analyses, still well within the desired possibilities for recovery and the imperfections of sampling, are performed routinely in connection with prospecting, testing prospects, and mining and extraction.

For almost all tests a sample is crushed and then pulverized to flour-like *pulp*. This is mixed thoroughly so that all constituents are distributed evenly, after which a portion is removed, weighed if necessary, and subjected to the appropriate test or tests. Tests that determine merely the presence of one or more elements are called *qualitative*, and those that estimate the amounts present are called *semi-quantitative* and *quantitative*. These terms are used with slightly different meanings by different authorities. Semi-quantitative tests are discussed with quantitative ones in this outline.

Qualitative Tests

Qualitative analyses were formerly made mainly by blowpiping or by chemical tests with acids and other reagents. These methods are still used (and fairly simple ones are described in Appendix VI) but have been supplanted largely by spectroscopic and X-ray fluorescence tests in laboratory work.

A spectroscope is an optical instrument in which a small part of a sample is burned in a flame or arc, from which rays characteristic of various elements fan through a prism or grating and appear as lines in a spectrum. Except for teaching purposes spectroscopes have been replaced by *spectrographs*, in which the bands are photographed for permanent record. Comparison with photographs produced by standard samples indicates the elements present. The relative intensities of the lines permit rough estimates of whether an element is present in high, medium, or low amounts. Spectrographic equipment is expensive, but, once obtained, qualitative and semi-quantitative tests can be made fairly rapidly and cheaply by qualified operators.

Qualitative spectrographic tests are often made before one proceeds with quantitative determinations of any kind, as they give some idea of which metals, if any, are worth determining quantitatively, and also indicate the presence of any elements that would interfere with certain tests; thus they help greatly in guiding quantitative work.

Quantitative Tests in General

Assaying is a general term covering tests to determine the quantities of metals present in samples from mineral deposits. It is derived from the old French word essai, meaning a trial. Assays were originally classed as *fire assays* (dry assays), in which part of the sample was melted and then subjected to various processes, and *wet assays*, in which a solution of part of the samples was tested in various ways. This is still a useful distinction, but other methods now available are often more suitable for particular kinds of samples or sufficient for the purpose required.

Fire Assaying

Fire assaying is done by melting a weighed amount of pulp in a clay crucible or dish placed in a small furnace. Added fluxes combine with unwanted elements to form a slag on top of the melt, and the metals to be determined sink to the bottom along with a metal added as a 'collector'. Fire assaying is now done mainly for gold, silver, and platinum, although other methods can be used for these metals. As lead is a good collector of gold and silver, it is added when assays are made for those metals. When cool, the lead carrying any gold and silver present is knocked away from the slag. The lead is then heated in a porous 'cupel' which absorbs the lead, leaving a bead of gold and silver. The bead is weighed; the silver is dissolved by heating the bead in strong acid; the gold residue is weighed; the amount of silver is determined by subtraction; and the assay is calculated, the ratio between a ton and the weight of pulp used being taken into consideration. Tin is used as a collector in fire assaying for the platinum group of metals, various subsequent steps being taken to determine the total amount of platinum-group metals present and to separate them if necessary.

A semi-quantitative method of assaying intended for prospectors to perform themselves, in which beads of certain metals are reduced from a sample by blowpiping, has been advertised. The amount is estimated by measuring the diameter of the bead and comparing it with a chart. In general, the writer does not consider this important for prospectors in Canada because mail service is now fairly good in most districts.

Wet Assaying

In classical wet assaying or analysis a solution of part of the sample is treated with chemical reagents to produce specific reactions that can be measured if certain elements or groups of elements are present. Such methods may be used for metals and non-metals. The amounts may be determined gravimetrically, titrimetrically, or colorimetrically. In gravimetric analysis, elements are precipitated and then treated to form a stable compound suitable for weighing; some elements are deposited as metals or oxides by electrolysis in forms suitable for direct weighing. In titrimetric work the volume of a solution of known concentration required to produce a certain reaction with the solution being investigated is measured. In colorimetric analysis use is made of the formation of coloured compounds of certain elements in solution, if one compares them by eye or photoelectrically with solutions of known concentrations. For example, this method is, or was, much used in routine assaying for copper at copper mines because the shades of colours of certain solutions are very distinctive within close ranges of concentration. Nowadays in large laboratories instruments called spectrophotometers are commonly used to measure the intensities of colours, and other aids include specially treated papers that produce characteristic tints when a little of a solution is placed on them. In addition to the three classical methods mentioned above, special instruments such as flame emission and flame absorption photometers, spectrophotometers and X-ray spectrometers, and emission spectrographs are now used. In the hands of qualified operators they give results as accurate as, and sometimes better than, conventional wet methods.

The ranges of accuracy obtainable in quantitative analyses vary according to the purposes for which they are required and the methods used. Classical analyses performed by the Geological Survey of Canada in connection with its own research in petrology, mineralogy, and geochemistry are made with an accuracy such that the final total of all the constituents is 100 ± 0.5%. More rapid analyses for many of its research projects yield 100 ± 2.5%.

Spectrographic Analyses

By comparison with carefully prepared standard samples, the quantity of a large number of elements can be determined by semi-quantitative or quantitative analysis. A densitometer is used to measure the intensities of lines on photographic plates or films on which the spectra are recorded. Some spectrometers are 'direct reading'. A disadvantage of spectrographic analysis, however, is the method is not as well suited to some elements as to others.

Accuracies of *semi-quantitative* analyses by one firm are stated to be such that, of a large number of samples, 95 per cent of the analyses would be within 50 per cent of the amount of an element present, while 95 per cent of its general *quantitative* ones would be better than ± 5 per cent, and with more refined techniques, ± 2.5 per cent.

X-ray Fluorescence Analysis

This method provides rapid qualitative and semi-quantitative determinations for elements with atomic weights heavier than that of silicon, or thereabouts, depending upon the instrument used. The method is not as suitable as optical spectroscopy for elements present in trace amounts and some kinds of samples, and the presence of certain elements causes difficulties. For many elements, however, sensitivities up to 0.01 per cent can be expected, and in favourable circumstances sensitivities of 10 to 50 parts per million have been obtained. In this method the atoms in a sample are excited by X-rays, and the resulting fluorescence is measured. The method is advantageous because the sample is not consumed as in other methods, although for most tests the sample must be powdered.

Radiometric Tests

Most assays for uranium and thorium are performed fairly quickly and with sufficient accuracy by instruments that measure the radioactivity of samples. More accurate wet and fluorimetric methods are used for establishing standards for radiometric work, for controls in exploration, mining, and extraction, and for research.

In almost all cases prospectors can, but in general have failed to, tell for themselves whether a sample is worth sending for assaying for uranium. This is done by testing the sample in its bag with an ordinary field radioactivity detector, at a place where the background is normal. If the sample raises the count to three or four times that of the background, or gives a corresponding reading with a scintillation counter, the sample probably merits assaying. This may be confirmed by having a few samples of various grades assayed to begin with, and the method is advisable for becoming familiar with a particular detector.

Rough semi-quantitative analyses for combined uranium and thorium can be made locally for remote exploration programs with fairly simple equipment including a balance, a small tray to hold a constant volume of pulverized sample, a few radioactive standards, and a meter-equipped radioactivity detector. Rejects from samples assayed in a laboratory form suitable standards.

Simple equipment can be arranged for making semi-quantitative tests on diamond-drill core.

Laboratory assays for uranium are most commonly performed with elaborate equipment which counts the rays emitted from a shielded tray containing a constant volume of pulp, for a definite length of time. The simplest of such tests are inaccurate if any uranium present is out of 'equilibrium' with its disintegration products, and they do not distinguish between uranium and thorium. These tests are reported as 'per cent U_3O_8 equivalent', and are satisfactory as an indication of whether more refined tests are justified. If so, these are generally done radiometrically by methods that allow for disequilibrium and distinguish fairly closely between uranium and thorium.

Control assays and routine assays at operating mines may be performed by different methods. In the widely used fluorescence method the pulp is fused with flux to form a pellet. When subjected to ultraviolet light the pellet fluoresces with measurable intensity varying with the uranium content. Some mines and laboratories use other methods for high-grade samples.

Radiometric tests are discussed more fully, with references, in "Canadian Deposits of Uranium and Thorium" (*Geol. Surv. Can.*, Econ. Geol. Ser. No. 16, 2nd ed.).

Obtaining Assays

The normal way of obtaining assays and other tests is through a firm that specializes in this work. A number of such firms advertise in the mining press. Commercial rather than research accuracies are generally provided. These should be quite satisfactory for almost all prospecting and mining purposes. Misleading results have sometimes been reported by unskilled technicians, particularly for the more unusual metals.

Most producing mines are equipped for making large numbers of assays to commercial standards of accuracies, as these are required for day to day operation. On the other hand, most companies doing prospecting or exploring mineral deposits have their samples assayed by commercial firms, unless they are also producing companies, in which case they may send their samples to their own laboratories. Some of these are equipped for spectrographic and other tests, and can perform analyses for research if required. Companies having their own facilities occasionally do a little assaying for independent prospectors with the hope of participating in a discovery.

Limited assaying is carried out for prospectors by some government departments, as a means of promoting mineral discovery. This is done almost entirely by provincial governments, some of which allow for a small number of free assays when a prospector's license is purchased, and charge for additional work. Others make free qualitative tests but charge for quantitative ones. The administration of the Yukon and Northwest Territories provides fifteen assay

coupons to persons working under its Prospectors' Assistance Program. The British Columbia Department of Mines and Petroleum Resources holds examinations and issues licenses for persons who practise assaying in the province, both for the public and for mining companies.

The Geological Survey of Canada and the Mines Branch of the Department of Energy, Mines and Resources do not perform assays or analyses except for their own research projects.

The best way to ensure satisfactory results commercially is to deal with established firms of good reputation, staffed by personnel of proven competence and preferably by at least one graduate chemist or an equivalent person. Unless the sender of samples knows that tests for only one or a few elements are wanted, the number of elements to be determined and the choice of method may be left for the assayer to decide. If desired, these matters and the cost can be settled by interview or correspondence before the work is authorized.

In view of the high cost of testing mineral deposits by drilling or other means, it would be unwise to try to economize on assaying, as so much depends on having an adequate number of samples assayed competently. Savings can, however, be appropriately made for large programs by having most samples assayed by one of the more rapid methods, and some by more accurate means as controls.

Prospectors and companies sometimes send material to two or three firms to check the reliability of assays. In doing so it is of little use to send different portions of an unpowdered sample, or both halves of split diamond-drill core, because they can differ widely in mineral content. Few deposits are of such even distribution as to make such procedures practical. A more appropriate way is to send the sample to one firm and to ask that the unused pulp be returned; after careful mixing this could then be sent to one or two others.

Estimation of Tonnage and Value

Full estimates of the tonnage and value of a deposit are made by mining engineers or geologists after detailed exploration has been done. The subject is not discussed extensively here, but it is desirable for prospectors to know the general principles involved, to help in obtaining an idea of the worth of a discovery or deposit on which they have done preliminary exploration, and to help them understand mining reports.

When several representative samples have been taken the results are averaged to provide an approximation of the average grade. If the widths across which the samples were taken are similar, the assay results may be added together and divided by the number of samples, to give what is called an 'arithmetical average'. If, however, the sampling widths are different, each assay result should be multiplied by the width for that sample, the figures so obtained added, and the total divided by the sum of the widths. Such an average, called a 'weighted average' is more reliable than a mere arithmetical average. The following example shows how such averages are computed, and their differences.

Suppose that five samples taken at 10-foot intervals from a vein of variable width gave assays in gold that had the following values and corresponding widths: $20 across 5 feet; $10 across 10 feet; $15 across 7 feet; $22 across 3 feet; and $40 across 2 feet. The values multiplied by the widths are:

Width	Assay	Width x Assay
5	$20 per ton	100
10	10	100
7	15	105
3	22	66
2	40	80
27	107	451

The average width is $27 \div 5 = 5.4$ feet

The weighted average is $451 \div 27 = \$16.70$

On the other hand, the arithmetical average is $107 \div 5 = \$21.40$

When assays are being averaged, if a few are much higher than the remainder it is generally assumed that the high ones are 'erratics' that are too high to be used because they would greatly affect the average. They are generally reduced to a more conservative figure. An average calculated after erratic assays have been reduced is called a 'cut' average.

To calculate tonnage, if samples were taken at close intervals, each line sampled may be assumed to represent the width of the deposit for a block extending halfway to the adjacent sampling lines, and this length is multiplied by the width. If samples have been obtained at depth, by drilling or underground exploration at reasonable intervals, widths and assays are often assumed to be representative for half the vertical or sloping distance between sampling places. This distance multiplied by the width and horizontal distance give the estimate of the volume for that particular block. The volume is multiplied by a factor representing the number of pounds per cubic foot for that type of rock or ore, and in this way the tonnage is calculated. The results are sometimes stated in terms of the entire block, and sometimes as tons or dollars per vertical foot. For detailed estimates the calculations are usually much more complex than the examples outlined above, and in addition they usually take into consideration ore that must be left for support, and dilution caused by the unavoidable inclusion of some waste rock during mining.

It should be remembered that the widths used must be the true widths, at right angles to the dip and strike of the deposit. If an outcrop or trench slopes so that the true width cannot be sampled, or if a drill-hole or underground working intersects the deposit at an angle, a correction for true width must be made. Diamond drilling may give misleading results in this regard, for if the hole intersects the deposit at a considerable angle from the perpendicular, a long intersection may be obtained from a relatively narrow deposit.

The following simple definitions of ore and its classes are based on fairly general usages. Detailed classifications are undergoing considerable discussion.

Ore is a mineral substance that can be mined at present at profit to the operator or to the benefit of the nation. In exceptional cases where a company continued to operate

a mine to minimize a loss the material mined would be considered ore.

Measured (Proven) Ore — This is ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, or drill-holes, and for which grade is computed from adequate sampling. The sites for inspection, sampling, and measurement are so closely spaced, on the basis of defined geological character, that the size, shape, and mineral content are well established.

Indicated (Probable) Ore — This is ore for which tonnage and grade are computed partly from specific measurement, samples, or production data, and partly from projection for a reasonable distance on geological evidence. The openings or exposures available for inspection, measurement, and sampling, are too widely or inappropriately spaced to outline the ore completely or to establish its grade throughout.

Inferred (Possible) Ore — This is ore for which quantitative estimates are based largely on knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. Estimates are based on assumed continuity or repetition for which there is geological evidence; this evidence may include comparison with deposits of similar types. Bodies that are completely concealed but for which there is some geological evidence may be included.

Potential Ore — This includes mineral deposits, the mining of which depends on improved prices, improvements in methods of mining or treatment, transportation facilities, etc. This material may be classified in the same way that ore is classified, or it can be treated much more generally.

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individual metals and minerals

This chapter deals with metals and industrial minerals and rocks as commodities. Besides providing general information the individual sections are intended to help persons to decide what to prospect for, and to aid them in forming an opinion of the merits of an occurrence discovered or indicated by an assay or identification. Some of the commodities discussed are of no value to prospectors, but information on them is desirable because persons wonder about their possibilities when they are mentioned in publications or assay reports.

The sections are arranged alphabetically, according to the principal products of various deposits. The advantages of grouping metals separately from non-metalliferous minerals, and of dividing the sections according to major and minor products were considered, but a general alphabetical arrangement seemed to have most advantages. In the previous edition of this book major and minor products were grouped separately but now, although this distinction has some meaning, the annual values of production are not readily separable into two such groups. The more important metals or minerals are, however, discussed at greater length. The longer accounts begin with a brief general statement, followed by notes on the principal minerals concerned and the types of deposits that have proved to be most significant in the past. In many notes one or more outstanding Canadian examples not described in earlier chapters are outlined, or previous statements are explained more fully. Unfortunately, only a few examples can be included. Some of the deposits so described are discussed more fully in *Geology and Economic Minerals of Canada*, a volume in the same series as the present publication. Because *Geology and Economic Minerals of Canada* contains numerous illustrations, the descriptions in this chapter are not supplemented by diagrams or photographs. The notes also include references to some of the other extensive literature on individual deposits. Some of these references are to papers in the two volumes on *Structural Geology of Canadian Ore Deposits* published by the Canadian Institute of Mining and Metallurgy, which also contain descriptions of many other deposits not mentioned in this chapter.

The ways in which some outstanding deposits were found and developed are discussed because these are not only of historical interest but may also provide lessons for the future. Even those discoveries that were made long ago, when the conditions of prospecting were much different from those of today, may help to illustrate points that modern prospectors should understand.

Most sections include comments on the outlook for the near future. These cannot be more than approximate opinions because demands, prices, uses, methods of treating ores, and other factors change; sometimes they change abruptly. These notes should therefore be supplemented by up-to-date advice included in courses, in articles in mining newspapers or magazines, or in the reviews on individual metals and minerals published annually by the Department of Energy, Mines and Resources and listed at the end of most sections of this chapter.

Many sections include information representative of production and prices for a recent year. Such statistics quickly become outdated; their only purpose here is to show the general situation. Figures for later years can be obtained from the annual reviews.

The sections deal mainly with metals because these are of interest to many conventional prospectors. Most industrial minerals and rocks are also discussed, as well as gems and meteorites. Industrial minerals and rocks comprise a large and important part of Canada's mineral production, but in general they are not of so much concern to the average prospector as are metals, because they commonly have low unit values and because the specifications are commonly so exacting that it is difficult for anyone but a specialist to judge whether a particular deposit is suitable. Some conventional prospectors have, however, become familiar with the requirements for certain industrial deposits and have devoted considerable attention to searching for them. In some instances a company, knowing of a demand for a certain industrial mineral or rock, will send a specially trained man to prospect or to examine reported occurrences which are close to transportation and where the geology is favourable. For these reasons, although prospectors should not ignore industrial mineral deposits, most readers will probably be concerned mainly with searching for metalliferous deposits.

Two or more metals or mineral products are commonly produced from a single deposit or from different deposits at what is essentially one mine. In such cases deposits are usually discussed in the section on the most important product concerned, but this is not always practical. For example, some deposits containing roughly comparable amounts of lead and zinc may be discussed in either section.

Deposits that contain three or more commercially recoverable metals are commonly called *multi-metal* deposits. Two or more metals produced in roughly equal proportions are called *co-products*, and metals or minerals produced in smaller amounts that are not vital to the operation are called *by-products*. In some cases the co-product of greatest value may occur in much smaller quantity than another co-product. For example, in many deposits containing both gold and copper the gold is only a small part of the total

volume of the ore, whereas the chalcopyrite responsible for the copper forms a much greater proportion of the volume. If the gold content is worth more than the copper content the deposit is commonly called a gold–copper one, and vice versa. Because certain parts of deposits may be different from the remainder, and for other reasons, a certain amount of latitude in these usages is to be expected.

Only a few of the many references available on individual commodities can be listed, but as these include still more references a reader could thus begin to obtain much data on an item of special concern to him. To avoid many repetitions the annual reviews prepared by the Mineral Resources Branch of the Department of Energy, Mines and Resources are identified by *Min. Res. Br.*, and those by the Industrial Minerals Sub-division of the Mineral Processing Division of the Mines Branch of this department are identified by *Min. Proc. Div.*

ABRASIVES

Several hard minerals and rocks, such as corundum, garnet, pumice, and sandstone are used as abrasive powders, grindstones, sandpapers, and other aids to cutting and polishing. However, artificial products such as silicon carbide and fused alumina have replaced many of the natural abrasives. Mainly for this reason the only natural abrasives produced in Canada are silica and beach sand, iron oxide, feldspar, granite, and grindstone, mainly as co-products of operations for other materials. Several known deposits of various kinds are not being worked. Therefore it is not likely to be profitable to prospect exclusively for abrasive materials, but large deposits encountered incidentally, particularly those containing corundum, might be of interest.

Total Canadian production of natural abrasives is valued at about $100,000 annually. Large amounts of industrial diamonds and diamond dust are imported.

Suggestions for Additional Reading

Carlson, H.D.
1953: The origin of the corundum deposits at Craigmont, Ont.; *Proc. Geol. Assoc. Can.*, vol. 6, pt. I, pp. 19–27.

Eardley-Wilmont, V.L
1927: Abrasives: products of Canada; *Mines Branch, Repts.* Nos. 673, 675, 677.

Stonehouse, D.H.
Abrasives; *Min. Proc. Div.*, Ann. Rev.

ALUMINUM

Canada is the third largest producer of aluminum, the use of which has increased greatly in recent years. Although the annual output is now nearly one million tons, no aluminum ore is mined in this country or is likely to be in the foreseeable future. Canada's place in world aluminum trade is based on her abundant and relatively cheap electric power close to seaports, as large amounts of electricity are required for the smelting. Statistics for aluminum production in this country are included in manufacturing, not mining categories.

Aluminum is the most abundant metal in the earth's crust, but occurs chiefly in the form of silicates, such as the feldspar minerals that are a main constituent of granitic rocks and the sedimentary rocks and clays that result from their erosion. Although methods of extracting aluminum from silica-bearing clays and feldspars have been developed in the laboratory they cannot be treated economically under present conditions. The commercial ore of aluminum is bauxite, a term used to describe aggregates of hydrous aluminum oxides, in the form of the clay minerals gibbsite, boehmite, and diaspore together with impurities, which are suitably low in silica. Bauxite deposits are formed by the slow surface weathering of rocks, chiefly in tropical and sub-tropical countries. It is unlikely that commercial grades of bauxite will be found in Canada, for if any deposits had been formed before the Ice Age they would almost certainly have been destroyed by glacial action, as bauxite is soft. Bauxite or ore that has been refined to form pure aluminum oxide is brought to this country mainly from Surinam, British Guiana, Jamaica, and Guinea.

Suggestions for Additional Reading

Jackson, W.H.
Aluminum; *Min. Res. Br.*, Ann. Rev.

ANTIMONY

Occurrences of stibnite (antimony trisulphide) and various sulphur–antimony minerals are fairly common in the Cordilleran and Appalachian regions. They are not now being mined because an adequate supply of antimony is obtained as a by-product of the smelting and refining of lead and other ores, and the world supply is greater than the demand. Canadian production is in the form of lead containing as much as 35 per cent antimony, used mainly for making lead alloys and produced at Trail, B.C. This plant can also produce metallic antimony but has not done so since 1944.

The antimony content of Canadian production in 1967 was about 1,243,000 pounds valued at about $658,800.

Suggestions for Additional Reading

Dawson, A.S.
1947: Antimony in Canada; *Can. Mining J.*, vol. 68, no. 1, pp. 20–21.
A short account of the economics and sources of antimony, of known Canadian occurrences, and the possibility of further developments in Canada.

George, J.G.
Antimony; *Min. Res. Br.*, Ann. Rev.

McClelland, W.R.
1950: Notes on antimony deposits and occurrences in Canada; *Mines Branch*, Mem. Ser. No. 108.
A summary of information on antimony occurrences in Canada up to 1950.

ARSENIC

Virtually all the arsenic used is a by-product of the treatment of metallic ores containing arsenic. Several mining and smelting plants in Canada have to recover arsenic to prevent dangerous fumes from escaping. As the supply is

greater than the demand there is no incentive to prospect for arsenic or to consider it an asset in ores mined for other metals.

Suggestions for Additional Reading

Ross, J.S.
Arsenic; *Min. Res. Br.*, Ann. Rev.

ASBESTOS

Asbestos is the principal industrial mineral mined in Canada; production in 1967 was valued at more than $163 million. This country was for many years the world's leading producer but in recent years she has been exceeded by the Soviet Union. Apart from its well known uses in cloths and other insulating materials, asbestos has been used in large quantities in recent years for manufacture of asbestos-cement pipes, shingles, sheeting, and other products. Still more recently it has been used as an additive in paving compounds, special papers, and as fillers and reinforcements in plastics.

The principal asbestos mineral is chrysotile, a fibrous variety of serpentine formed by alteration of ultrabasic rocks. Most Canadian asbestos is produced near Thetford Mines and Black Lake in the Eastern Townships of Quebec, where mining has been continuous since 1878. Sir William Logan first described asbestos occurrences in this area in a report on investigations in 1847–48, and repeated the information in "Geology of Canada, 1863". He also helped to interest persons in beginning mining of asbestos, by exhibiting and explaining specimens at international exhibitions. Most mines are worked by open-pit methods, and great reserves remain despite the large tonnages produced in the past. During the last few years these mines have been greatly expanded and modernized. In addition, mines in Ontario, Newfoundland, and British Columbia produce asbestos fibre and one in Yukon Territory was inaugurated in 1967. Many other Canadian occurrences of different varieties of asbestos are known, but to be economically attractive an asbestos deposit must be of high quality and contain adequate reserves of material of ore grade.

Quebec

Asbestos was found near Des Plantes River in the Eastern Townships about 1862, but attempts to work the small deposits there failed. In 1877 the mineral was found near Thetford and mining on a small scale was begun the following year. It was difficult to find a market at first, but as the characteristics of asbestos became better known and as new uses were developed, rapid expansion took place over the next twelve years.

Chrysotile is found in peridotite that has been altered to serpentine, which occurs with pyroxenite in sill-like and stock-like masses in a narrow interrupted zone, commonly referred to as the Serpentine Belt, which extends northeastward for about 150 miles from the Vermont border. Still farther northeast, small areas of similar rocks occur but have not yielded commercial grades of asbestos. In the Thetford area are peridotite lies mainly within the Caldwell group of Cambrian age, but it also intrudes Ordovician strata. The age of the intrusions is therefore probably late Ordovician and related to the Taconic period of mountain building.

The chrysotile is of two types, called cross-fibre and slip-fibre. The former, which accounts for most of the production, occurs in veins with cleancut walls, the fibres arranged parallel with one another and at a high angle to the walls or normal to them. The veins are generally from a fraction of an inch to 3 inches wide. Vein matter that is more than $\frac{3}{8}$ inch wide is called 'crude' and is selected by hand, whereas shorter material is milled, the rock being crushed, beaten and screened and the asbestos separated by overhead suction. The milled variety amounts to more than 99 per cent of total production. The cross-fibre veins are of two types, one containing a single set of fibres running from wall to wall, and the other containing fibres extending from each wall and meeting at a central fissure that may contain serpentine similar to the wall-rock, and magnetite. Both types occur throughout the deposits. The walls of the veins consist of serpentine that grades into the ordinary partly serpentinized peridotite. This border zone is lighter in colour than the surrounding rock, and the edges are sufficiently sharp to enable the rock to split readily along them. The width of the altered zone including the asbestos vein in the middle, is commonly from 6 to 8 times the width of the vein itself. The slip-fibre type occurs in much-sheared serpentine, the fibres being matted and lying more or less lengthwise along the shear planes.

F.J. Alcock has summarized the probable origin of the deposits as follows:

> It is probable that the rocks were serpentinized originally at a late stage in their consolidation, as a result of reaction between the mineral constituents and associated magmatic water. Though associated with the peridotite the asbestos is quite clearly of later origin. Veins cut across pyroxenite dykes and across masses of chromite in the peridotite. At one place a granite dyke was found to contain inclusions of peridotite, and in one of these inclusions was a vein of asbestos 3 feet long and with a maximum width of $\frac{3}{4}$ inch running out from the peridotite into the surrounding granite. The veins are related to fault fissuring, and apparently were formed by vapours travelling along the fissures, converting the walls into serpentine. The presence of magnetite suggests that this alteration took place at high temperatures. From the fault fissures the vapours penetrated the pores of the rock, and wherever they encountered incipient fractures they reacted with the peridotite, converting the walls into serpentine and carrying some of the excess material into the fissures to be deposited as asbestos. It is probable that this second period of serpentinization and the production of the asbestos are related to the Devonian orogeny and accompanying intrusions.

A deposit northeast of Chibougamau was being tested by underground workings in 1967.

Ontario

Production began in 1950 from a large deposit of chrysotile asbestos in Munro and Beatty townships, 10 miles east of Matheson, in the region north of Kirkland Lake. This mine was closed in 1964. Another mine near Matheson began to produce in 1965 and a mine is being developed near Timmins.

British Columbia

The Cassiar asbestos mine on McDame Mountain in the northern part of this province began production in 1953. The deposit contains chrysotile in a mafic rock, probably Jurassic in age, which is so altered to serpentine that its original nature is doubtful. A large body of chrysotile-bearing rock was outlined by the company optioning the claims from the prospector, and tests showed that the mineral was of such high quality that the deposit could be mined profitably despite the distance from markets. A branch road was built to join a road leading to the Alaska Highway, and a mill with an initial capacity of 150 tons a day began operation in 1953. This was increased to 500 tons a day in 1954, 1,000 tons in 1956, 1,500 tons in 1960. Over 72,000 tons of fibre were produced from the Cassiar mine in 1967.

Yukon Territory

A deposit at Clinton Creek, discovered in 1957 in a general area where asbestos has been known to occur for many years, was brought into production in 1967.

Newfoundland

A deposit near Baie Verte was discovered in 1955 and brought to production at 5,000 tons a day in 1963.

Outlook

Although the Eastern Townships contain reserves of asbestos sufficient for many years, good deposits of asbestos will probably continue to be in demand. Occurrences associated with serpentinized ultrabasic rocks are fairly common in the Appalachian and Cordilleran regions and the Canadian Shield. To be of interest a deposit must contain enough veins of asbestos spaced sufficiently closely to permit mining a large mass of rock, and the asbestos itself must have suitable qualities. This cannot be determined by having samples assayed, as for metalliferous occurrences; the quality must be estimated by an expert. If a deposit seems to be of reasonable asbestos content and total size, samples could be submitted to a provincial or federal mining department or an asbestos-producing company.

Suggestions for Additional Reading

Findlay, D.C.
1967: Clinton Creek Mine; in the mineral industry of Yukon Territory and southwestern District of Mackenzie; *Geol. Surv. Can.,* Paper 67-40, pp. 27–29.

Hewitt, D.F., and Satterly, J.
1953: Asbestos in Ontario; *Ont. Dept. Mines,* Industrial Mineral Circular No. 1.

This report describes asbestos minerals and their mode of occurrence, gives information on economics and marketing, and describes the principal occurrences known in Ontario.

Riordon, P.H.
1962: Geology of the asbestos belt in southeastern Quebec; *Trans. Can. Inst. Mining Met.*, vol. 65, pp. 182–184.

Ross, J.D.
1931: Chrysotile asbestos in Canada; *Mines Branch*, Rept. 707 (out of print).

A comprehensive report on mining for asbestos in Canada up to 1931. It includes information on asbestos minerals and deposits in Canada known up to the time of publication.

Winer, A.A.
Asbestos; *Min. Proc. Div., Mines Branch*, Ann. Rev.

BARITE

Barite (barium sulphate) is produced in large quantities in Canada, mainly for export. The heaviness of this mineral makes it especially useful as an ingredient in the mud required during the drilling of oil wells and for other uses such as fillers in paint, rubber, linoleum, and paper.

The principal Canadian production is from Walton, N.S., where a replacement deposit in limestone-conglomerate of Mississippian age is reported to contain a large reserve. Two deposits are also worked at Parson and Brisco, B.C., and barite is recovered from tailings at Spillimacheen, B.C. Occurrences are known in several parts of Canada. It seems unlikely that prospecting specifically for barite would be worth while at present, but if a large deposit were found close to reasonably cheap transportation, it would probably receive attention. Barite is said to leave white streaks on a steel rod used as a probe. Canadian production in 1967 was about 200,000 tons valued at more than $2 million.

Suggestions for Additional Reading

Reeves, J.E.
Barite; *Min. Proc. Div.*, Annual Review.

Ross, J.S.
1960: The barite industry in Canada; *Mines Branch*, Info. Circ. 1C 126.

Spence, H.S.
1922: Barium and strontium in Canada; *Mines Branch,* Rept. No. 570.

Tenny, R.E.
1951: The Walton barite deposit; *N.S. Dept. Mines*, Ann. Rept., pt. 2, pp. 127–143.

BENTONITE

Bentonite is a kind of clay formed by the alteration of volcanic ash. Good grades of bentonite swell eight to fifteen times their volume when soaked in water, whereas others do not swell but have great absorptive properties. Bentonite therefore has many uses, such as in "mud" used in drilling for oil and gas, binder in moulding sand, filters, bleaching clay, and filler in numerous manufacturing processes. A large amount has been used recently as a binder in iron pellets, but the bentonite used in Canada for that purpose is imported.

The main producing deposits are two in Alberta and one in Manitoba, where beds in different formations of Mesozoic age in the Interior Plains contain sufficient bentonite to be mined commercially. Other occurrences are known in these provinces and in British Columbia and Saskatchewan, therefore bentonite is not of great interest to prospectors, but a large well-situated deposit might repay investigation if it proves to have the right properties.

Canadian consumption of bentonite has risen greatly in recent years, but production from Alberta has declined.

Suggestions for Additional Reading

Ross, J.S.
Bentonite in Canada; *Mines Branch,* Monograph 873.

BERYLLIUM

Beryllium is a light metal, very desirable for certain special alloys. Beryllium–copper alloys for springs and electrical contacts are still a basic market. Beryllium–aluminum alloys show promise for lightweight structural applications. Beryllium metal has shown more growth in structural application than in atomic energy uses. Beryllium is not a nuclear fuel but would be desirable for certain related uses if enough were available at reasonable prices. Another growing market has been use of beryllium metal powder in rocket propellants. The ore, mainly hand-cobbed beryl, is in adequate supply and prices are in the order of $320 per ton delivered to U.S. ports. Demand for additional deposits is not strong at present. There has been no significant Canadian production, and the small amounts produced in other countries have come mainly from beryl (a silicate of beryllium and aluminum) obtained from pegmatite deposits that were being mined also for mica, feldspar, lithium, or niobium. Few pegmatite deposits contain enough beryl to be worked for beryl alone. Beryl is occasionally found in the gangue of tungsten and tin deposits.

Much beryl does not have the characteristic pale-green colour and is difficult to distinguish visually from quartz and some other minerals. Chemical and other field tests are described in the papers listed below. An instrument called a beryllometer that registers neutron emission from beryllium after subjection to rays from a radioactive source has been developed and manufactured in Canada, but its expense and the precautions required have limited its use to special projects.

Beryl has been found at more than seventy-five localities, mainly in the Canadian Shield and less commonly in the Cordilleran and Appalachian regions. Almost all are in granite pegmatites and related deposits, and beryl has been stockpiled at a few. An occurrence of the rarer mineral helvite has been found in magnetite-rich skarn in limestone near a granitic contact in northern British Columbia.

Suggestions for Additional Reading

Beus, A.A.
Beryllium: evaluation of deposits during prospecting and exploration; San Francisco and London, W.H. Freeman and Co.

Mulligan, R.
1960: Beryllium occurrences in Canada; *Geol. Surv. Can.*, Paper 60-21.
1968: Geology of Canadian beryllium deposits; *Geol. Surv. Can.*, Econ. Geol. Rept. No. 23.

Rowe, R.B.
Beryllium — information for prospectors; *Dow Chemical of Canada Limited*, Res. Dept. Cont. No. 45.

Vokes, F.M.
1958: Metallogenic map, Beryllium in Canada; *Geol. Surv. Can.*, Map 1045A-M 2.

BISMUTH

Bismuth is a minor metal used chiefly as a constituent of certain alloys, mainly those in which low melting-points are desired, as in fuses. All commercial supplies of the metal are recovered as a by-product in the refining of certain lead, zinc, copper, and molybdenum ores. No commercial ores of bismuth alone are known.

Canadian production in 1967 amounted to nearly 546,000 pounds valued at about $2 million.

Suggestions for Additional Reading

George, J.G.
Bismuth; *Min. Res. Br.*, Ann. Rev.

CADMIUM

Cadmium is used chiefly for plating other metals, particularly to prevent corrosion. It is closely related to zinc and occurs in small quantities in most zinc ores, which are the only commercial source of cadmium, the metal being recovered as a by-product from zinc smelters. No commercial ore of cadmium alone is known.

Canadian production in 1967 was about 4,772,000 pounds valued at about $13 million.

Suggestions for Additional Reading

Fraser, D.B.
Cadmium; *Min. Res. Br.*, Ann. Rev.

CALCIUM

Calcium is produced from lime by Dominion Magnesium Limited, Haley, Ontario. The output in 1965 was about 160,000 pounds valued at $153,000. This relatively small production is because of limited demand, although abundant sources are available.

CESIUM

This metal is not produced in Canada but a short account of its occurrence is included here because there is some interest in it. Cesium is used in certain photoelectric devices. The principal source is pollucite, a compound of cesium, aluminum and silicon oxides, and water. It occurs in complex, generally well-zoned, lithium-bearing pegmatites, the principal known deposit in this country being at Bernic Lake in southeastern Manitoba. This deposit is also of interest for tantalum. A simple chemical field test is included in the second publication listed below by permission of the Manitoba Department of Mines and Natural Resources.

Suggestions for Additional Reading

Howe, A.C.A., and Rowntree, J.C.
1967: Geology and economic significance of the Bernic Lake pegmatite; *Bull. Can. Inst. Mining Met.*, Feb., vol. 60, no. 658, pp. 207–212.

Mulligan, R.
1961: Pollucite (Cesium) in Canada; *Geol. Surv. Can.*, Paper 61-4.

CHROMIUM

Chromium is important as an alloying ingredient in stainless and corrosion-resistant steels, and also for electro-

plating. The only source of economic importance is the mineral chromite, an oxide of chromium and iron. The relative amounts of chromium and iron vary in different deposits, the chrome–iron ratio being an important factor in determining the economics of an occurrence, because deposits low in chromium are uneconomical unless the material can be treated to bring it to market specifications. Good ores and concentrates contain about 50 per cent chromic oxide and have a chromium–iron ratio of about 3 to 1.

Chromite occurs in several districts in Canada but no deposits of commercial grade are known. Most of the chromite used in Canada is imported from Africa and the Philippine Islands. A little is produced in the United States, and during World War II some was produced from deposits in the Eastern Townships of Quebec. Although the market has been essentially unchanged in recent years, political unrest in other parts of the world might cause increased demand for deposits in North America.

Chromite is associated with ultramafic igneous rocks, such as dunite, peridotites, and pyroxenites, and with the serpentines to which they alter. Masses or scattered grains of chromite may be found, usually in the rock called dunite, that is sometimes mistaken for chromite. Grains of the latter, however, are shiny, whereas dunite is a fine-grained, grey-black, iron-magnesian rock of dull appearance, which where scratched displays a pale-grey streak. Usually the only other metallic mineral present is magnetite, which closely resembles chromite but is easily distinguished by its strong magnetic property and black streak, whereas the streak of chromite is chocolate-brown.

Discovery of a large chromite deposit of good grade in Canada would be important, and many efforts have been made to find one, especially in wartime. Places of interest to the prospector are the serpentine areas, especially those of the Eastern Townships, Quebec, and of central British Columbia, and parts of the Canadian Shield where ultrabasic rocks occur. Southeastern Manitoba became an area of special interest in 1942 with the exploration of deposits in the Bird River region, where chromite is found in peridotite. This chromite has a low chrome–iron ratio and in the past research has been carried on without success to develop a commercial method of treatment that would make an acceptable product.

Suggestions for Additional Reading

Craig, J.W.
1940: Chrome for Canada; *Trans. Can. Inst. Mining Met.*, vol. 43, pp. 762–780.

This paper summarizes the world-wide occurrences, uses, and treatment of chromium ores, as well as the Canadian occurrences and trade as they were in 1940.

Downes, K.W., and Morgan, D.W.
1951: The utilization of low-grade domestic chromite; *Mines Branch*, Mem. Ser. No. 116.

This report describes the results of research on several methods of utilizing low-grade chromite deposits such as have been found in Canada, and it discusses possibilities for further exploitation of such deposits.

Stockwell, C.H.
1944: Chromite deposits of the Eastern Townships, Quebec; *Trans. Can. Inst. Mining Met.*, vol. 47, pp. 71–86.

This paper describes the geology and chromite deposits of the Eastern Townships where most of the small Canadian production of chromite has been obtained. It includes notes on prospecting possibilities.

Wigle, G.P.
Chromium; *Min. Res. Br.*, Ann. Rev.

CLAYS AND CLAY PRODUCTS

Clay products, such as building brick, valued at $43½ million in 1967 and made from domestic common clays and shales form a substantial part of Canadian production from industrial minerals. Although large deposits are known, additional ones of suitable specifications situated in areas not now well supplied would probably be of interest.

Deposits of high quality are classed as china clay (kaolin), fireclay, ball clay, and stoneware clay. As few such deposits are known in Canada, clays of these kinds are usually imported, and might be worthy of the attention of prospectors well versed in the qualities required. Much attention has, however, already been given to the search. Deposits of white china clay might be found in unconsolidated material suitably concentrated or weathered by natural processes, but such deposits would be more likely to occur as residual material derived from the weathering of rocks in place, rather than in the transported overburden found in most parts of Canada. A large deposit of china clay, in England, is associated with bedrock and apparently the result of alteration of granitic rock at high temperature. Suitable deposits of this general kind may yet be found in Canada. Kaolin-bearing rock containing excessive amounts of silica and other impurities has been found in various parts of Quebec, Northern Ontario, Manitoba, and Saskatchewan. Fireclays, ball clays, and stoneware clays occur as sedimentary deposits.

Suggestions for Additional Reading

Brady, J.G.
Clays and clay products; *Min. Proc. Div.*, Ann. Rev.

COBALT

Cobalt has important uses, mainly for making special alloys. Canada was formerly a leading producer of cobalt as a by-product of silver mining at and near Cobalt, Ontario, and some is now produced in this way because of the revival of the Cobalt camp, but main production is from Africa. Cobalt is also produced as a by-product of nickel–copper mining at Sudbury, Thompson, and Lynn Lake. Canadian output in 1967 was about 3,306,000 pounds valued at nearly $7 million.

Several occurrences, generally associated with nickel, copper, or native silver are known in the Canadian Shield and the Cordilleran and Appalachian regions.

Workable deposits will probably be in demand for some time. The pink colour of cobalt bloom (erythrite) is a useful guide for prospecting.

Suggestions for Additional Reading

Jones, R.J.
1954: Cobalt in Canada; *Mines Branch,* Report No. 847.
This report contains information on Canadian occurrences, production, metallurgy, uses, and world trade.

Wigle, G.P.
Cobalt; *Min. Res. Br.*, Ann. Rev.

COPPER

Copper is one of the most widely used metals. Because of its corrosion resistance, ductility, and electrical and thermal conductivity, much copper is used in tubes, sheets, wires, and cables. It is easily alloyed with other metals to form strong, easily worked, corrosion resistant alloys of pleasing appearance. Canadian production of copper in 1967 was about 1,185,000,000 pounds valued at nearly $564 million. In value of production, it was the leading metal in this country in that year, second only to petroleum in the entire mineral industry. Canada was fifth among the world's copper-producing countries. Ontario was the leading copper-producing province, followed in order by Quebec, British Columbia, Manitoba, Saskatchewan, Newfoundland, and New Brunswick.

Minerals

Chalcopyrite (copper and iron sulphide) is by far the main Canadian ore mineral for copper. Chalcopyrite, and malachite and azurite, the two common supergene copper minerals, are the essential copper minerals that a prospector must be able to recognize. Malachite and azurite are not sufficiently abundant in most Canadian deposits to account for significant production, but they are often useful guides, because of their characteristic green and blue colours, to the presence of chalcopyrite or other primary copper minerals in outcrops. Malachite or azurite may be particularly helpful in calling attention to low-grade disseminated deposits in which the primary minerals might not be obvious; in some instances only a little primary copper will cause a fairly extensive film of malachite or azurite which makes the surface or fractures of an outcrop appear to have been painted green or blue.

In certain regions chalcocite, native copper, tetrahedrite, or bornite are or have been significant ore minerals. Ability to recognize these would be desirable, but not so essential as chalcopyrite, malachite, and azurite unless a prospector intends to work in particular regions in which they are likely to be significant.

Deposits

In the last few years about three-quarters of the copper produced in Canada has come from mines in the Canadian Shield and the remainder from mines in the Cordilleran and Appalachian regions. About half the copper produced from the Shield came from nickel–copper mines, mainly in the Sudbury area, and the other half came mainly from massive and disseminated strata-bound deposits most of which contained zinc as a co-product along with recoverable quantities of gold, silver, and, in some cases, other metals. Most of the productive strata-bound deposits of the Shield are in Superior Province where most mines of this kind are in a belt of altered volcanic and sedimentary strata that includes the Timmins, Noranda, and Matagami areas. Several fairly similar mines are producing or have produced in the Flin Flon and Snow Lake areas in the southern part of Churchill Province.

The typical multi-metal deposits of Superior and Churchill Provinces are lenticular, massive, and disseminated sulphide bodies containing various proportions of pyrite, pyrrhotite, sphalerite, chalcopyrite, gold, and silver; some also contain galena and other metalliferous minerals. Most mines are operated on two or more orebodies spaced fairly closely. The average grades of ore range from about 0.5 to 5 per cent copper and 0.5 to 11 per cent zinc; several mines have sections having different grades, and some have orebodies that are mainly valuable for copper and others that are mainly valuable for zinc. The deposits in the Timmins–Noranda–Matagami region are in a thick succession of altered volcanic and sedimentary strata intruded by large and small masses of plutonic rocks. Many of the deposits are in mafic volcanic rocks at or near their contact with more salic, underlying volcanic rocks. Most deposits of the Flin Flon–Snow Lake region are in volcanic rocks of intermediate to mafic compositions, or their metamorphosed equivalents. The first sulphide deposits found in all these regions were the result of conventional prospecting but, because the terrains are covered extensively by overburden, most more recent discoveries have resulted from advanced methods of prospecting; some have been found beneath barren rock. The first orebody found in the Manitouwadge area was confirmed by prospectors investigating an occurrence of sulphides indicated on a map published by the Ontario Department of Mines in 1932. Most deposits in this area are in strongly metamorphosed sedimentary rocks, a point worth emphasizing because, before the Manitouwadge area became productive, prospectors generally considered that the highly metamorphosed belts of volcanic and sedimentary rocks in the Shield were not as favourable as those of more moderate metamorphism.

About a dozen mines are now producing copper in the Chibougamau region. They differ from the deposits described above because they are essentially copper–gold types without significant zinc, they are shear-zone fillings and veins, and they occur mainly in gabbro and related rocks. The Icon deposit, a fairly recent discovery in the northern part of the region, is a strata-bound chalcopyrite deposit in Aphebian dolomite.

Veins containing chalcopyrite, bornite, and native copper occurring in fault zones in late Precambrian basalt and conglomerate are being mined north of Sault Ste. Marie. These have some of the characteristics of deposits being tested actively in the Coppermine region of the Northwest Territories. Chalcocite is the main mineral in most of the Coppermine deposits, which are veins and breccia zones in the late Precambrian Coppermine River group of basaltic flows.

Most of the copper produced in the Appalachian region is derived from multi-metal sulphide strata-bound and vein

deposits. Lenticular pyritic deposits containing various amounts of chalcopyrite, sphalerite, or other sulphides, in the Eastern Townships, occur in schists and other rocks of Paleozoic age. Formerly they were generally thought to be related to Devonian granitic intrusions in the district, but they may instead be the result of volcanic or sedimentary processes related to the deposition of their enclosing strata. The original Gaspé copper deposit consists of chalcopyrite–molybdenite bodies along faults in a skarn zone in Devonian shale and limestone. The ore mined in 1967 averaged 1.12 per cent copper. The nearby Copper Mountain deposit, being prepared for production in 1968, bears some resemblance to porphyry–copper deposits; its main sulphides are pyrite and chalcopyrite, with minor molybdenite and other minerals, occurring in skarn and granite.

In most of the strata-bound sulphide deposits of Bathurst area, New Brunswick, copper is subordinate to zinc and lead but the Wedge is mainly a copper deposit, carrying 3 per cent copper and 1.75 per cent lead.

Copper in grades ranging from 0.7 to 1.6 per cent is the main metal of the Little Bay, Whalesback, Baie Verte, Tilt Cove, and Gullbridge mines in Newfoundland. Most of these are lenses and shear-zone deposits containing several sulphide minerals as well as chalcopyrite, in metamorphosed basic volcanic strata and ultramafic rocks of Paleozoic ages.

Copper occurs in many places in the Western Cordillera, in British Columbia, and Yukon Territory. Most deposits are in basic volcanic strata containing plutons of granite and related rocks. The principal types of deposits are: massive and disseminated bodies related to shear zones and showing some evidence of replacement; 'porphyry-copper' deposits consisting of replacements and fracture fillings in brecciated plutonic rocks which are not necessarily porphyritic; contact metasomatic deposits some of which also contain commercial quantities of magnetite; and vein deposits of various kinds. The first deposits mined were contact and vein deposits in the 'Boundary' district immediately north of Washington state. Here the Rossland gold–copper veins occurred in volcanic flows and sills intruded by granitic rocks, and the contact deposits of Phoenix and other camps were irregular bodies of skarn in limestone and other sediments. After these camps waned most of the copper mined in British Columbia came from large deposits at Britannia, Anyox, and elsewhere that have usually been considered shear-zone deposits. The Britannia ores are in a large mass (roof pendant) of sedimentary and volcanic rocks in the Coast Range batholith. In recent years the grade of ore has been about 1.5 per cent copper and 0.9 per cent zinc, with some gold and silver. The deposits at Anyox were in a roof pendant of amphibolite in the Coast Range batholith; up to the closing of the mine in 1936 the ore contained 1.2 to 2.3 per cent copper and some gold and silver. The Copper Mountain deposit, the first large one of the general porphyry–copper type to be mined in British Columbia, contained about 1 per cent copper, mainly bornite, disseminated in a stock that ranges from gabbro at its margin to copper-bearing syenitic pegmatite at its centre. Not far to its north the Bethlehem deposit, which has been known in a general way for many years, was brought into production in 1962 as a result of further investigations and improved markets. Here chalcopyrite, bornite, molybdenite, and other minerals occur in brecciated granitic rocks that are partly porphyritic; ore reserves are based on a cut-off grade of 0.35 per cent. Several other deposits of this general type, some including parts that are contact metasomatic, have recently been brought into production or are being developed in British Columbia.

History

Interest in copper in Canada has been active longer than in any other metal because natives used 'slugs' or nuggets of native copper in pre-historic times. Pieces of native copper that had been weathered out of rocks or mineral deposits could occasionally be found fairly easily lying on the ground or in the gravels of streams, and they could be hammered to form knives, spearheads, and arrowheads. The first white explorers noted that the natives had such implements and in 1770 an attempt was made by a fur trader and missionaries to mine native copper near Sault Ste. Marie; a few years later an attempt was made to mine copper in Newfoundland, but both efforts were unsuccessful.

The first significant lode mining in Canada for any metal, other than small-scale mining of iron ore for local use, took place at Bruce mines on the north shore of Lake Huron in 1848 and continued intermittently until 1921. This discovery resulted from a spreading of interest in copper along the Great Lakes following the establishment of copper mines in Michigan in the 1840's; these were among the earliest mines in United States.

Copper was found in Quebec in 1840. In that year Sir William Logan, who was to found the Geological Survey of Canada two years later, was told while travelling through the Eastern Townships that tin occurred on a mountain near Sherbrooke. On investigation he saw that a copper, not a tin, mineral was present. He returned to the area a few years later to make a more detailed study and indicated in his report three places that seemed particularly favourable. Prospectors followed this advice and in each case found deposits, the first of which began to produce about 1855. Although the original mines are worked out the copper belt of the Eastern Townships is still an important producer.

Mines in various parts of Newfoundland have supplied substantial amounts of copper at different times from 1864 to the present. The first was the Tilt Cove, which is credited with having been found after Sir William Dawson, one of the first Canadian geologists, suggested that the rocks there were favourable for the occurrence of copper.

The exploitation of large copper deposits found in the 'Boundary district' of British Columbia, just north of the 49th parallel, made that province the leading Canadian producer of copper in the last years of the 19th century and early in this one. Mines in other parts of British Columbia continued to make that province the leader in copper mining for most years until 1933, when Ontario took the lead it has kept.

Copper has been known to occur in the Chibougamau

region, which is in the Canadian Shield in northern Quebec, since 1870 when a member of the Geological Survey of Canada crossed the region during a reconnaissance of the canoe route between Lake St. John and Hudson Bay. Although several occurrences of copper and gold were found there when this report was followed up soon after the turn of the century, the area was too remote for mining until a railroad was built. This permitted the opening of the Opemisca copper deposit in 1954 and several others in later years. Meanwhile prospectors spread from the Timmins and Kirkland Lake gold districts into neighbouring parts of Quebec. Edmond Horne discovered a large copper deposit, as a result of prospecting he carried on there from 1911 to 1920. This became the Horne mine of Noranda Mines Limited, which began its long productive history in 1927. This deposit, together with others subsequently found in the area, make the Noranda area one of the world's great copper camps. In 1955 the Noranda company also inaugurated the Gaspé copper mine in the interior of Gaspé Peninsula. Production from another great copper–zinc district was begun in 1930 with the completion of a smelter at Flin Flon, on the Saskatchewan–Manitoba boundary.

In the period 1956–66 new copper mines brought into production in Canada totalled fifty-seven; this was more than for any other metal. These were mainly in Superior Province of the Canadian Shield and in British Columbia. This was nearly one-third of all the mines of any kind initiated during that period. A notable feature of these recent copper mines is that almost all were in old copper-mining camps or areas containing old prospects, which were rejuvenated because of improved methods of prospecting and testing prospects, improved prices and markets, and improved methods of mining and treating ores. These factors permitted the mining of material of much lower grades than formerly, although in some districts ores of higher grades were also found. In some cases mineralized rock left in old mines became economically mineable, in others advanced methods of searching for extensions of old orebodies or new bodies close to old ones were successful, and in still others advanced methods revealed independent ore deposits in areas where minor copper prospects had been known for years. A few deposits were, however, discovered by advanced methods in what can be considered new areas, such as the Poirier between Noranda and Chibougamau, and the Icon north of Chibougamau.

In 1967 much interest was revived in the possibilities of the Coppermine area because of the current emphasis on copper and because of general improvements in northern transportation. Copper deposits have been known here since 1771 when Samuel Hearne made one of the epic journeys of Canadian exploration. As a young apprentice of the Hudson's Bay Company he was sent out from the present site of Churchill to spend two years travelling by foot with a band of Indians, to check native reports of a large copper deposit. He found native copper near Coppermine River, but in quantities disappointingly small for those times. They have been investigated at various times since then, mainly in 1943–45 when sizable deposits were indicated by diamond drilling.

Outlook

Both the short-term and the long-term outlooks for copper seem favourable. Canadian prices varied from 45 to 51 cents a pound in 1967 and demand was strong. The world situation was made uncertain by political unrest in some of the main copper-producing countries and by strikes in others. For some of its principal uses copper would be difficult to replace by substitutes, but for other uses metals such as aluminum could be substituted, and in some cases plastics are challengers. For these reasons large producing companies have tried to prevent large rises in prices resulting from the present demand, because such rises would tend to switch some demands to substitutes.

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DIATOMITE

Diatomite is a sedimentary deposit resembling chalk, composed of silica in the form of the 'shells' of microscopic organisms called diatoms. It has many industrial uses as a filter, absorber, and insulating material. About half the diatomite now used in Canada is employed as a coating on grains of chemical fertilizer, to keep them from sticking together.

More than four hundred deposits of diatomite are known in Canada, but the small and sporadic production has been virtually confined to deposits of recent age in Nova Scotia, and Tertiary age near Quesnel, B.C. The latter are the only ones being worked at present. They are said to include the largest commercially acceptable deposit in Canada, for which increased production and a new plant were announced.

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FELDSPAR AND NEPHELINE SYENITE

Feldspar is used mainly in the manufacture of pottery, glass, porcelain, enamelware, and cleansing powders. It was formerly obtained from numerous small open-pit operations on pegmatite dykes, but prospecting for feldspar is of no interest at present because the demand is small and many known deposits in accessible places are not being worked. If, however, a pegmatitic deposit were being considered as a large source of some other product, it might be desirable to investigate the possibility of feldspar as a co-product. The only production of feldspar itself now is from a large coarse-grained granitic pegmatite deposit near Buckingham, Quebec, where about 11,000 tons valued at $255,000 were mined in 1966.

In recent years nepheline syenite has been preferred to pure feldspar in the glass industry because of its higher content of aluminum oxide. A large deposit at Blue Mountain near Peterborough, Ontario, is worked by two companies. It is in the southern part of the Grenville province of the Canadian Shield. Nepheline occurs in syenite, gneiss, and pegmatite in various parts of the Canadian Shield and the Cordilleran region. Exploitation has been hindered by variable nepheline content, excessive iron content, and other factors, but the possibility of finding suitable deposits near a potential market, particularly in western Canada, should not be ignored. Canadian production in 1966 was about 366,000 tons valued at $4 million.

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FLUORSPAR

Fluorspar or fluorite (calcium fluoride) is an important mineral for the manufacture of flux used in smelting aluminum, as a flux in the making of steel, and as a raw material for producing fluorine chemicals. The demand is growing but although Canadian production is considerable almost all goes to aluminum-producing plants. About the same amount is imported for use in other Canadian industries. The principal mine is at St. Lawrence, Newfoundland, where fluorspar occurs in veins and stringer systems in granite. It is also produced as a by-product from a silica quarry near Oliver, B.C. Small mines have been worked for fluorite elsewhere in British Columbia and at Madoc, Ontario. A deposit is being developed at Lake Ainslie, N.S. Several other occurrences are known in other parts of the country, but only large deposits in accessible places, and otherwise suitable, are likely to be important.

Production in 1966 was valued at about $1.9 million.

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GALLIUM

Gallium is mentioned briefly here because it is common in minute quantities, which are often reported in analyses, although it is not likely to be of importance to prospectors.

Gallium is closely related to germanium and is about as abundant as lead as a constituent of the earth's crust, but it does not tend to form natural concentrations and is known only as an impurity in certain minerals. The limited demand is filled from by-product production in other countries.

GEMS AND RARE MINERALS

The more valuable gems, such as diamonds, rubies, and emeralds have not been found in Canada in commercial deposits, but specimens of some of the minor gems, semi-precious stones, and minerals desired by lapidaries and collectors have been found in several parts of the country. It is rather surprising that the more important gems have not been found, because geological conditions more or less similar to those in which some of the principal gem deposits of the world are found do exist. It should be noted, however, that the market and value of some naturally occurring gems are not as attractive as they once were, because methods of making synthetic stones of high quality have been developed. These are not imitations, but true synthetic stones of the same compositions as natural ones, and the relative ease and cheapness of their production have affected the demand for the natural stones.

Diamonds are found in other countries in 'kimberlite', a breccia composed of rock fragments in a matrix of serpentine and carbonate. This is an unusual rock, and it must be remembered all rocks containing serpentine are not necessarily favourable for the occurrence of diamonds. Occurrences of kimberlite and related rocks recently found in Canada have revived interest in the possibilities of finding diamonds. Most other gems occur originally in pegmatites, particularly those pegmatites relatively high in lithium and sodium. Several semi-precious stones such as lapis lazuli and jade are found in contact metasomatic deposits in limestone, schist, or gneiss.

A large part of the world production of gems comes from placers, because most gems are hard and resistant to erosion even if they are not particularly heavy. Therefore gems originally contained in deposits of the kinds mentioned in the previous paragraph tend to be concentrated in beach and other forms of placers. Often they are derived from sporadic occurrences that could not have been worked economically in their primary state, and have been concentrated by slow natural processes, just as many important gold placers are derived from very lean gold-bearing rocks. Gems may therefore be found in Canadian placer deposits, particularly in the Cordilleran region.

No discussion of the possibility of finding gems in this country would be complete without mention of the many attempts to discover the source of the famous Wisconsin diamonds. At least seventeen diamonds were reportedly found in glacial drift in Wisconsin and nearby states before the end of the last century, and there is good reason to believe that they were transported from one or more occurrences in the Canadian Shield. Repeated attempts have been made to find the source, sometimes by fairly elaborate expeditions and after careful study of the probable directions of glacial flow and deposition. All attempts have failed, but it is not impossible that by luck or by further knowledge of glacial processes diamonds may be found in the Canadian Shield. Articles on this subject are listed below. The only other suggestions of diamond occurrences in this country were reports of microscopic-sized diamonds in the Bridge River and Tulameen regions of British Columbia, but later work showed that the supposed diamonds were synthetic periclase formed by heating samples of rock.

Minor gems, and semi-precious stones such as amethyst, occur in several parts of the country, and material suitable for ornamental purposes, such as agate, can be found in many places, either in bedrock occurrences or as pebbles and boulders. Jade of the nephrite variety has been found as boulders in British Columbia and Yukon Territory. A deposit in place was found after a systematic search in the Fort St. James area in 1968.

On the basis of present information it would not seem that prospecting for gems alone is likely to be very rewarding, but prospectors may find it to their advantage to learn something of the characteristics and modes of occurrence of gems and semi-precious and ornamental stones, and to be alert for occurrences of them when prospecting for other metals and minerals. At least they should learn to recognize garnets and small transparent crystals of quartz, rutile, etc., which are common and almost always valueless, and which are often submitted to government agencies by persons who think they are rubies or diamonds. Another point to be noted is that the quality of gem minerals varies greatly. Therefore it is far from sufficient merely to have a mineral identified as a species that is sometimes of gem quality; it is often necessary to have the quality estimated by a jeweller or a mineralogist who specializes in gems.

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GERMANIUM

Germanium is used in the manufacture of transistors and rectifiers for use in electronics circuitry. No commercial deposits of germanium have been discovered in Canada but the possibility of its occurrence as a minor constituent of other ores and of coal should not be ignored.

Germanium occurs in germanite and argyrodite, sulphides of silver and germanium, but these minerals are not common and they have not been found in Canada.

Germanite and other minerals containing germanium have been found in other countries in ores mined for zinc, lead, and copper, germanium being recovered from the flue dusts of certain smelters that treat these ores. It is believed that germanium might also be found in small amounts in titanium and tin deposits. It occurs in small quantities in certain coals, and in the United Kingdom is recovered from the flue dusts of producer-gas plants. Reports suggest that adequate supplies can be obtained from these by-product sources.

Small amounts of germanium have been detected in zinc ores of the Sullivan, Kicking Horse, and Monarch mines and in carbonaceous material in sandstone on Lang Creek in British Columbia. It is reported to occur with hematite in a zinc–lead deposit in the Gaspé Peninsula in Quebec and was reported recently from a zinc discovery on Cape Breton Island, N.S. Investigations at Canadian smelters have failed to find economic quantities of germanium in the flue dusts.

Many samples of coal from different parts of Canada have been and are being tested for germanium by the Department of Energy, Mines and Resources and other organizations. The results to date indicate only scattered occurrences even within a single mine.

GOLD

Gold was the first metal mined in quantity in Canada, but the value of production of some other metals exceeded that of gold early in the present century. Then, during the depression in the 30s prices and demands for other metals declined, the price of gold was increased, and it again became the principal metal, the value of its production reaching a peak in 1941, when 5,345,000 ounces worth $205,789,000 were mined; this included $2,700,000 in placer gold. Since then increasing costs and the fixed price of gold have caused a great decline, the production for 1967 being about 3 million ounces valued at more than $112 million. The average price per ounce paid by the Canadian Mint in 1967 was $37.75. Many mines were closed during the last few years, and few new ones were opened. Relatively little attention has been paid in recent years to prospecting for gold or to testing gold prospects. Several potential properties are being held in case of an eventual change in conditions.

History

As explained in more detail in the chapter on placer deposits, the first large production of gold in Canada was in the Appalachian region of Quebec, where placer mining began in the basin of the Chaudiere River in 1847. A few years later discoveries of rich placers in British Columbia began a large production of alluvial gold in the Cordilleran region. This kind of mining reached its peak at the turn of the century as a result of the Klondike discoveries in Yukon Territory. Since 1900, when gold to the value of $22 million was taken from the Klondike alone, Canadian production of placer gold has gradually declined.

During the period of great interest in placer mining in the west it was natural that some men would turn their attention to prospecting for lodes, and that many quartz veins and other gold-bearing lode deposits would be found. Even before the placer rush, a little lode gold was mined on one of the Queen Charlotte Islands in 1852. Twenty years later an arrastra was used in an attempt to work a lode gold deposit in central British Columbia. A stamp mill was built in the Cariboo district of British Columbia in 1876 but this attempt to work gold–quartz deposits had little success. Near the end of the century, however, important gold-bearing lodes were brought to production in southern British Columbia, largely as a result of the impetus given by the building of the Canadian Pacific Railway. Most important were the replacement veins containing gold and copper in the Rossland camp, where production began in 1894 and a large output was obtained from 1897 to 1916. Another important producer, the Nickel Plate mine at Hedley, began production in 1903 and for a time was the largest gold mine in Canada. The Nickel Plate ores were gold-bearing contact metasomatic deposits in limestone, containing much arsenopyrite. These mines, together with several smaller ones, made British Columbia the leading province in the production of lode gold during the early years of the present century.

Important gold mining was carried on in Nova Scotia for many years on gold–quartz veins in slates, generally along the crests of anticlines. These veins occurred in the Gold-bearing Series, a thick succession of quartzites and slates considered to be late Precambrian by some geologists, and Cambrian by others. The veins are believed to owe their

origin to granitic intrusions of Devonian age. Production began in 1862 and started to decline about 1904, but reached a new high in 1939, largely as a result of the 1934 revaluation of gold by the United States. Output has since declined greatly.

The first discovery of gold in the Canadian Shield took place in 1866 not far from Madoc in southeastern Ontario. Other discoveries in this region soon followed, and after the building of the Canadian Pacific Railway in 1886 between Port Arthur and Winnipeg, small mines were brought into production in both regions, but they did not challenge the position then held by British Columbia.

After Sudbury and Cobalt became established, respectively, as great nickel–copper and silver camps the importance of the Canadian Shield as a source of minerals began to be better realized. Prospectors and financiers turned their attention to the area in greater numbers, thus beginning a succession of important gold discoveries that has continued to the present. The first of these was what became the Porcupine camp. A geologist of the Ontario Department of Mines had found traces of gold in quartz veins there as early as 1896, and in his report recommended the area to prospectors. The first discovery by a prospector was in 1906, but the important discoveries that became the Dome, Vipond, and Hollinger mines were made in 1909. Regular production began at the Hollinger in 1912. Other important mines came into production in the district from time to time, making the Porcupine camp one of the great gold producers of the world.

The Porcupine discoveries caused prospecting to spread eastward and westward in the more accessible parts of the Shield. The first great gold camp discovered after Porcupine was Kirkland Lake, where early finds were made in 1911 and 1912. Production began in 1915, and as additional mines began operating and tonnages were increased, the camp gradually came to rank with Porcupine as a major gold area.

The depression that began in 1929 and lasted until about 1939 caused an extraordinary expansion of gold mining, at first because gold had a steady market at a fixed price at a time when prices of other commodities fell, and later because the official price of gold was raised by the United States in January, 1934, from $20.67 to $35 an ounce. Many new mines were brought into production in Quebec, Ontario, Manitoba, Saskatchewan, and the Northwest Territories; the last great camp to be developed was Yellowknife, where production began in 1938. Some of these were new discoveries and others were known formerly but were not sufficiently attractive at the former price of gold. In addition, many of the mines that operated successfully at the old price had substantial amounts of lower grade material that could be mined profitably at the new price. Canadian gold production reached its peak in 1941, when 5,345,179 ounces valued at $205,789,392 were produced; this included about $2,700,000 worth of placer gold. During these years, gold held an envied place in the Canadian economy.

After 1941 gold production declined, at first because of difficulties in obtaining supplies and labour during World War II, and subsequently because of rising costs and the depletion of ore reserves. Despite financial aid provided to gold mines by the federal government through the Emergency Gold Mining Assistance Act to offset these difficulties, there has been a steady decline in the number of operating lode gold mines since 1960. By 1966 production had fallen to 3,319,474 ounces valued at $125,177,364, although Canada maintained her position as the second greatest gold producer in the free world. South Africa continued to rank first with a production of 30.5 million ounces. There has been little prospecting or exploration for gold in Canada and few new mines have been opened recently.

The amount of gold used for industrial purposes has been increasing in recent years. Substantial quantities are also used in the arts. However, the use of gold as a medium of exchange continues to be its most important use. Central bankers at a meeting in March 1968 agreed to a two-price system for gold. Under the arrangement, central bankers use the existing reserves of monetary gold for settlement of trade balances between nations concerned at a fixed price of $35 per ounce in United States funds. Gold reserves are not to be increased or depleted by buying or selling in the free market. The price of gold in the free market is determined by supply and demand. Changes in international monetary policies that may affect the price of gold are difficult to predict. So long as present conditions prevail, production will probably continue to come from most of those gold mines now operating, but prospecting and exploration for gold will probably be less attractive than for other metals. In 1968, mines classed as essentially lode-gold producers totalled thirty-eight. Also, several mines worked mainly for other metals produced gold; such mines might become the main source of gold in future if demands and prices for it remain unattractive.

Deposits in the Canadian Shield

At present the Canadian Shield accounts for about nine-tenths of the Canadian production of gold, the remainder coming mainly from the Cordilleran region. For many years, Ontario has been the principal producer, followed by Quebec. In 1968, mines operating at 100 tons a day or more comprised twenty in Ontario, nine in Quebec, seven in Northwest Territories, one in British Columbia, and one in Manitoba, not including mines that produced gold as a by-product. The largest was the Kerr-Addison, in the Larder Lake area of Ontario, which formerly operated at 4,500 tons daily but whose output has declined since 1960. Some mines were closed in 1967.

The gold deposits of the Canadian Shield differ greatly in details, but they fall into three broad categories. One type, naturally enough, consists of gold quartz deposits that may be large quartz veins or aggregates of many irregular veinlets and lenses. In some the gold is visible and free milling, but much of it is of microscopic size and often occurs in grains of sulphide minerals. Another type consists of altered rock, commonly schist, containing disseminated gold, frequently associated with sulphide minerals; some of these deposits are in shear zones. Many mines contain

bodies that are mixtures of both these types, with gold occurring both in stringers and lenses of quartz and in the intervening rock, so that large bodies can be mined economically. The third type consists of large sulphide orebodies mined mainly for copper and other base metals (such as the orebodies of the Sudbury and Noranda districts) that yield substantial amounts of gold.

The principal gold deposits of the Shield occur in belts of early Precambrian greenstones or sedimentary rocks, or both. Although gold mines are scattered widely in the Shield, the main ones are in three belts. One of these extends through the Porcupine camp, is represented by a few additional deposits farther east in Ontario, and extends into Quebec, where it contains the Beattie mine and other deposits. Another belt, about 100 miles long, includes the mines at Kirkland Lake, several of which are worked on what is really a single long deposit. This belt continues, with deposits spaced intermittently, through the Larder Lake district in Ontario and for many miles in Quebec, where it includes the Noranda, Malartic, and Val d'Or regions. Many of the orebodies in each of these belts are associated with bodies of quartz–feldspar porphyry, syenite porphyry, or other intrusive rocks, and the orebodies are commonly related to prominent faults and shear zones that provided access for the intrusion and the ore-bearing solutions. A third belt, called the Yellowknife Gold Belt, includes the important Giant Yellowknife and Con-Rycon orebodies in Northwest Territories, which lie in large shear zones displaced by a prominent post-mineral fault.

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GRAPHITE

Graphite is used for foundry facings, heat-resistant and corrosion-resistant articles, pigments, lubricants, and the so-called 'lead' in pencils. Many recently developed uses, such as in certain kinds of atomic reactors, are based on synthetic graphite, which is particularly suitable. No significant production of natural graphite has taken place in Canada since 1954.

Graphite occurs at many places in limestone and gneiss in the Grenville province of the Canadian Shield. The Black Donald mine near Calabogie, Ontario, produced large amounts of 'small flake' and 'amorphous' grades of graphite from a contact metasomatic deposit in Grenville limestone until work was suspended in 1954. Smaller amounts of the same grades were produced several years ago from deposits in and near the Ottawa valley in Ontario and Quebec. The possibility of finding other workable deposits in Canada is somewhat worthy of the attention of prospectors but such deposits would have to produce very high quality graphite or yield it as a by-product because the market is small and difficult to enter.

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GYPSUM

Canada is the world's third largest producer of gypsum; her production in 1967 was about 5 million tons valued at nearly $11 million.

Gypsum (hydrous calcium sulphate) is formed by the evaporation of sea water in shallow basins, the deposit being incorporated as lenses or beds in sedimentary formations. Gypsum is mainly used in the manufacture of plaster and plaster products and in the production of Portland cement. Anhydrite (anhydrous calcium sulphate) is commonly associated with gypsum deposits. It is used, to a limited extent, as a fertilizer and soil conditioner and also in Portland cement. Most Canadian deposits of gypsum are in Paleozoic formations. The principal Canadian production is from beds associated with red shale and limestone of the Windsor group of Mississippian age, in Nova Scotia. The mineral is also produced in Ontario, Newfoundland, British Columbia, Manitoba, and New Brunswick, in that order.

Gypsum is not likely to be of great concern to prospectors for the following reasons: (1) occurrences are widespread and fairly well known and (2) should additional deposits be desired they will probably be developed by diamond drilling along zones outlined by geological studies. Discovery of suitable deposits near large centres that lack known commercial deposits close at hand would, however, be important.

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INDIUM

A little indium is commonly found in ores of zinc, lead, tin, tungsten, and iron, the most common association being

with sphalerite. It is recovered in the metallurgical plant at Trail, B.C. Indium is used in small amounts as an alloying ingredient and for other purposes, but it is not likely to add appreciably to the value of zinc or other ores, or to be of interest to prospectors.

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IRON

Iron is the basic ingredient of steel, which is the foundation of modern industry. Canadian production of iron ore has increased steadily in recent years and was valued at more than $455 million in 1967, when it was our fourth leading mineral. Canada is the fourth largest producer, after the Soviet Union, United States, and France. About 85 per cent of Canadian output is exported, mainly to the United States. The greatly increased importance of iron ore mining in Canada has been largely due to expanded markets abroad, and improved methods of concentrating the ores and shipping in bulk.

History

Many years ago settlements in Quebec and Ontario were supplied with iron by small local charcoal furnaces that smelted limonite from bog iron deposits and magnetite from small deposits in the southern part of the Canadian Shield. As soon as transportation facilities were improved it became cheaper to import iron and steel from other countries, so these early mines were abandoned.

Small iron mines have been operated intermittently in the Appalachian region since 1848. Ore from the large Wabana deposits of Newfoundland was for many years smelted at the steel plant at Sydney, N.S., until the mine was closed in 1966.

Shipments of iron ore from the Texada Island mine in British Columbia were made to the United States from 1886 to 1908. This mine and several iron prospects in the same province, which were known for many years, were reactivated in recent years because of expanding markets for iron concentrates in Japan.

Iron deposits have been found in many places in the southern part of the Canadian Shield in Ontario, but most have been too small or too poor for profitable mining. The first to be worked successfully on a large scale was in Michipicoten district, where the Helen mine was worked from 1900 to 1918. This deposit was found in 1898 by a prospector named Goetz who staked a gossan as a possible gold discovery; it turned out to be an iron mine. No iron ore was produced in any part of Canada from 1925 to 1938. In 1939, large operations were resumed in Michipicoten district and have continued as a source of iron ore for the steel plant at Sault Ste. Marie.

Large deposits of high-grade ore, averaging about 54 per cent iron, were brought into production at Steep Rock Lake, 120 miles west of Port Arthur, in 1944 after an interesting history and an outstanding engineering achievement. Boulders of hematite were found on the shore of Steep Rock Lake during geological mapping in 1885, and it was concluded from their unglaciated appearance that they had not travelled far and probably came from a source later covered by the lake. The notes accompanying the map, published in 1897, contained the statement: "An iron-bearing horizon with hematite of good quality, appears to be generally covered by the waters of the lake". This report gave rise to much prospecting and staking in the area, but these early endeavours were unsuccessful. Further studies called attention to promising occurrences found in place, and thereafter a great deal of prospecting was done. A persistent prospector, Jules Cross, made a dip-needle survey of a part of the lake from the ice in 1930, and his backers provided funds to diamond-drill from the ice the anomaly his survey had indicated. The first important drill intersections were found in 1938. When a large body of good-grade iron ore had been outlined, the Seine River, which drained into Steep Rock Lake, was diverted by several dams and cuts, and the lake was pumped out to permit open-pit mining, which began in 1944. In 1953 development of an underground mine was begun, to obtain ore from parts of the main deposit that are too deep for open-pit operations. Production from other deposits in the district was begun more recently.

The history of the development of the Quebec–Labrador deposits also shows the importance of geological studies, as well as the long time often required before discoveries can be exploited, and the large expenditures and extensive engineering work involved. From 1892 to 1895, A. P. Low of the Geological Survey of Canada carried out geological explorations in Ungava and Labrador and reported the presence of large deposits of iron-bearing material in the basins of Hamilton and Koksoak Rivers, which he thought might be of economic importance at some future date. In 1929 a company undertook exploration of these and found deposits of good grade close to the scene of the present mine, but they were considered to be too remote in relation to the demand for iron ore at that time.

In 1936 another company, Labrador Mining and Exploration Company Limited, was formed to search for gold and base metals in this general region. Systematic geological studies and prospecting were done under the direction of J.A. Retty, who was the first to find iron ore on the Quebec side of the Labrador watershed. The work was continued by this company and, after 1942, by Hollinger North Shore Exploration Company Limited and The M.A. Hanna Company. When sufficient ore had been proved to warrant the building of a 358-mile railway from Seven Islands on the north shore of the St. Lawrence, Iron Ore Company of Canada was formed in 1949, by the three companies mentioned above and several large steel companies in the United States, for the purpose of building the railway and bringing the deposits into production. This was accomplished after an expenditure of about $250 million on exploration and construction. Thus in 1954, 60 years after Low's explorations, the first shiploads of iron ore left Seven Islands bound for steel mills in Canada, the United States, and Europe.

This successful development caused other companies to acquire concessions throughout the Labrador iron belt, which extends northwestward for about 500 miles and southward for 150 miles from Knob Lake. Much systematic prospecting, geological mapping, and exploration were done, and other mines were brought into production, including the large Quebec Cartier operation at the newly organized town of Gagnon. A second railroad was built to connect it with Port Cartier. Additional mines are being prepared for production.

In 1949 an aeromagnetic survey carried out by the Geological Survey of Canada for the Ontario Department of Mines revealed a strong anomaly near Marmora, close to the southern boundary of the Canadian Shield. Soon after the map was published, Bethlehem Steel Corporation acquired the ground and drilled it, revealing the presence of a large deposit of magnetite in much altered Precambrian limestone. This was removed to expose the ore and permit open-pit mining. An output of 500,000 tons of pelletized concentrates a year was begun in 1955.

A deposit of magnetite in amphibolite and amphibolitic limestone found near Bristol, Quebec, about 1870 was mined from 1884–94. It was re-opened as the Hilton mine in 1958 and continues to produce at a rate of 875,000 tons annually.

Space does not permit individual mention of several other important deposits that were brought to production during the last few years or that are being developed.

Iron Minerals

The principal minerals of iron ores are hematite (Fe_2O_3) and magnetite (Fe_3O_4), which are oxides of iron that occur together in some ores and separately in others. Also important in some ores are goethite (limonite), the hydroxide of iron; siderite ($FeCO_3$), the carbonate of iron; and chamosite, a hydrous aluminum silicate of iron. Most of the material generally called limonite is goethite with variable amounts of contained water.

Deposits

Iron is the fourth most abundant element in the earth's crust and is second only to aluminum among the metals. It occurs as a minor constituent of many rocks, mainly as magnetite, and in innumerable small mineral occurrences of many kinds. It is also common as sedimentary 'iron-formation', mainly of Precambrian age; although extensive, these deposits are generally below ore grade. The important types of deposits of the world are well represented in Canada.

The geological types of iron deposits and their origin and classification, together with the commercial specifications for ores, form a very large subject that can only be touched on here. Most of it is beyond the scope of ordinary prospecting and is readily available, for more advanced purposes, from the references listed and other sources. The following summary is condensed from "Geology of Iron Deposits of Canada."

Iron ores are divided into 'direct-shipping' and 'treated' ores. The former is suitable for use in blast furnaces after crushing and, perhaps, sizing. Many ores are now treated to form concentrates and agglomerates. Use of such methods during the last 10 years has resulted in greatly increased production and potential production. Concentrates are the result of such operations as washing, flotation, or gravity or magnetic separation which increase iron content and remove gangue. Agglomerates are produced from concentrates, mainly by sintering or pelletizing, thus forming material that is less likely to be partly lost in shipment or in the blast of a furnace. By-product material is recovered from treatment of some copper, lead, zinc, and titanium ores. Prices for iron ores vary greatly according to iron content, presence of desirable or undesirable elements such as manganese and phosphorous, respectively, and other factors. Preferred ores now contain 60 to 66 per cent iron, less than 6 per cent silica, less than one per cent lime, magnesia, or alumina, and very low contents of phosphorous or sulphur.

About nine-tenths of Canadian iron mines and potential ores are in sedimentary 'iron-formations' and other stratified deposits. Most of the remainder are contact-metasomatic magnetite deposits. Ordinary iron-formations contain three to ten times as much iron as the average content of the earth's crust. Commercial deposits contain still greater concentrations, either as unusual original depositions or as a result of concentration by natural processes such as the solution and removal of silica and carbonate by leaching. The largest production is from Proterozoic strata but important deposits occur in Archean and Paleozoic formations.

The deposits near Knob Lake in the Labrador Trough are of the so-called Lake Superior type that has been mined for years in Minnesota. They are concentrations of hematite and goethite in cherty iron-formation. Other commercial deposits in the Labrador Trough, which are called metataconite, are fine-grained iron-formation that has been recrystallized by metamorphism in such a way as to permit concentration without excessively fine grinding. Ores of the Steep Rock type were formed from buried residual accumulations of iron minerals on old erosion surfaces, later altered and redistributed to form masses of hematite and goethite. The ore now being mined at Michipicoten is iron-formation containing beds of fairly massive siderite and some pyrite and pyrrhotite. The Wabana deposits consisted of Paleozoic beds containing hematite, siderite, and chamosite in distinctive, small, rounded grains called 'oolites'.

The remainder of Canadian production, other than by-products, is derived mainly from contact metasomatic and high-temperature replacement deposits containing magnetite, commonly associated with skarns. They are smaller and generally more irregular and unevenly mineralized than sedimentary deposits. Many such magnetite occurrences are known, particularly in the Grenville region of the Shield and in the western Cordillera, but only the better ones have proved to be workable. Several of the Cordilleran deposits also contain important amounts of copper minerals. A recent addition to these producers is the Tasu mine in Queen Charlotte Islands, where a copper–iron deposit found in 1907 was opened in 1967.

Prospecting Considerations

The demand for iron deposits of large size and suitable qualities, particularly in accessible places, will probably continue but prices and export markets are expected to be more competitive.

Because iron ore has a relatively low unit value compared to other ores, only large deposits of high iron content and low-grade formations that are easily concentrated can be worked profitably. An iron ore mine must be capable of supplying daily, for a long period, thousands of tons of material sufficiently rich to warrant shipping, or of a type suitable for concentrating. Therefore, although iron occurrences are very common, only the best ones are likely to be of value in the near future. Prospecting for iron is usually done with the aid of geophysical instruments, in conjunction with geological studies. As it would be difficult for the average prospector working on his own to distinguish between important and unimportant deposits, it seems likely that most important iron discoveries in future will be made by scientists or prospectors working for companies, rather than by independent prospectors unless they are well qualified. Aeromagnetic maps have proved to be useful indicators of favourable locations for prospecting, and many geological maps show belts of iron-formation that may repay investigation. The recent discoveries of a large sedimentary deposit in late Precambrian or early Paleozoic age in Yukon Territory during mapping by oil company geologists, and of a large high-grade deposit in Archean iron-formation in Baffin Island as a result of an observation of distinctive exposures from an aircraft, suggest strongly that additional deposits remain to be found.

Much information on the occurrence of iron deposits and their evaluation is contained in the recent publications listed below. The metallogenic map included in one of them (Gross, 1965) should be useful to prospectors and companies actively concerned with searching for additional deposits or acquiring occurrences for further testing.

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LEAD

Canada is the western world's third largest mine producer of lead, one of the most useful of metals. It was one of the first metals used by man, because it was easily smelted from its ores by primitive means and because it was easy to cast. Leaden water pipes, joined by a lead–tin solder, were much used by the Romans; thus our word 'plumber' is derived from 'plumbum', the Latin word for lead. Today, lead's softness, weight, ductility, resistance to corrosion and radiation, and its alloying properties make it one of the chief industrial metals. Its principal present uses are in storage batteries, gasoline anti-knock compounds, sheathing for electrical cables, paints, ammunition, collapsible tubes, and mixed metals such as solder, babbit, and type-metal.

In 1967 Canadian production of lead totalled more than 643 million pounds, valued at about $90 million. This was obtained mainly from mines in Northwest Territories and British Columbia. Substantial amounts were also obtained from mines in New Brunswick and Newfoundland, and still smaller quantities were recovered in Ontario, Yukon Territory, Quebec, Manitoba, Saskatchewan, and Nova Scotia. No mine was operated for lead alone, most of the production being as a co-product or by-product of operations for zinc and, to lesser extents, copper or silver.

Minerals. By far the most important lead mineral is galena (lead sulphide). It is generally easy to recognize, unless occurring in fine grains, by its combination of steel-grey colour, heaviness, and cubic cleavage. Other primary minerals containing lead are of minor importance in Canada. The secondary minerals cerussite and anglesite may be present in the weathered parts of galena deposits but are not sufficiently characteristic in colour to be particularly useful guides for prospecting. Galena is so commonly associated with silver and zinc that its presence should always be suspected where silver or zinc minerals are encountered or assays showing these metals are obtained.

Deposits. Most of the lead produced in Canada has come from strata-bound sulphide deposits containing lead, zinc, copper, and other metals. Zinc is commonly more abundant than lead. In most deposits in the Canadian Shield lead is subordinate to zinc and copper; only a few deposits such as the Coniagus at Bachelor Lake in Quebec contain enough lead for it to be classed as a co-product, although lead is a by-product of several other deposits in the Shield. The large Kidd Creek silver–zinc–copper deposit produces substantial quantities of lead as a by-product. Several large strata-bound deposits in the Appalachian region contain zinc, lead, and copper, notably at Bathurst, New Brunswick. Strata-bound deposits in sedimentary rocks in western Canada are essentially lead–zinc or zinc–lead types, without significant copper. For many years deposits in the

Cordilleran region, including the Sullivan mine which is described below, supplied most of the output of Canadian lead. Recently, however, a large zinc–lead deposit at Pine Point, Northwest Territories, in the Interior Plains, has become the leading mine producer of lead; it is described in the section on zinc.

Many transgressive deposits of vein and replacement types contain galena, generally with silver minerals or sphalerite or both. They have been worked in the Cordilleran and Appalachian region and in the Shield. Although much lead, as an aggregate, has been derived from such deposits they have not yielded nearly so much as the total amount of lead produced from strata-bound deposits.

Sullivan Mine. Prospecting in the East Kootenay region, where the Sullivan mine is located, began about 1860 with the discovery of placer gold near Fort Steele. In 1892 a high-grade galena deposit was found by two prospectors in the hills west of Fort Steele. This, later known as the North Star mine, produced considerable lead and silver. In the same year, four prospectors named Sullivan, Smith, Cleaver, and Burchett became discouraged with their efforts in the vicinity of Kaslo and decided to travel across the Purcell Range to try their luck at Fort Steele. After a difficult back-packing trip of more than a month's duration, prospecting as they went and exhausting their supplies, they reached Fort Steele just when the North Star discovery was causing excitement. They decided to search on the hill across a small creek from the North Star, and Burchett soon found galena float which he followed until he found a deposit in place. They staked claims which they explored intermittently for four years and then sold for $24,000 to a group operating the Le Roi gold–copper mine at Rossland. This group began systematic development of the Sullivan deposit in 1900, after a branch of the Canadian Pacific Railway was built from Cranbrook to Kimberley. Ore was shipped to small smelters at Trail and Nelson until 1903 when a smelter was built near the mine. These early efforts met with little success, however, because the intimate mixture of the galena and sphalerite was not well suited to direct smelting. In 1909 the property was optioned to the Consolidated Mining and Smelting Company of Canada, (now Cominco Ltd.) which operated mines at Rossland and the smelter at Trail. This option was confirmed in 1910 and the new owners began selective mining and sorting to improve the quality of the ore shipped. At the same time, deep diamond drilling showed that the orebody was very extensive. The problem was to find a means of treating the large amount of material that had been found but which was not suitable for direct smelting.

By then a process called 'selective flotation' was coming to the fore as a means of separating the constituents of fine-grained ores. In this process the ore is ground to a pulp and fed into cells in which the pulp is agitated mechanically or by air blown into the cells, small amounts of frothing oils and various chemicals being added. If different oils are used and the process is controlled in various ways, certain mineral grains can be made to adhere to the bubbles that rise to the top of the cell and are skimmed off. The company saw the possibilities of this method for producing lead and zinc concentrates from the Sullivan ore, and after considerable research succeeded in adapting the process to it. The first unit of a concentrator was built in 1923, and since then the operation has been greatly expanded to its present 10,000 tons daily capacity.

The Sullivan deposit is in the late Precambrian Aldridge formation, which is composed mainly of interbedded argillite, siltstone, and quartzite. The deposit is generally considered to be composed essentially of replacements of certain beds, mainly argillaceous siltstone, which form an east-dipping stratigraphic zone 200 to 300 feet thick, mainly between an underlying band of conglomerate and overlying beds of quartzite. The ore, which is banded and contorted, consists mainly of galena, sphalerite, pyrrhotite, and pyrite, together with several non-metalliferous minerals. Individual orebodies in the zone are as much as 1,000 feet long and 200 feet thick at right angles to the dip.

Sills and other bodies of gabbroic composition, called the Purcell sills, intrude the sedimentary rocks in the vicinity of the mine. The available evidence suggests that these are of Proterozoic age. Granitic rocks, apparently Cretaceous or early Tertiary in age, are exposed about 10 miles from the deposit and may exist at depth closer to the mine.

Because of the importance of the deposit, its geology and origin have been studied intensively. Most investigators favour an origin by hydrothermal replacement, believing that the orebodies were formed in the belt of argillaceous rocks in which they lie because it was favourable for the circulation of solutions probably because of greater permeability and the lesser permeability of flanking strata. Faults that displace the strata may have played a part in providing access for the solutions. In spite of prolonged investigations, conclusive evidence has not been found that would date the period of replacement. Some evidence, in the district as a whole, seems to point to replacement associated with the Cretaceous or Tertiary period of granitic intrusion, but it may instead have been related to the earlier Purcell intrusives, or separate phases of the mineralization may have been related to each of these intrusive epochs.

A concentrating plant at the mine, having a daily capacity of 10,000 tons of ore, produced concentrates containing 88,861 tons of lead in 1966. The grade of the ore is not published specifically, but the owners reported that the combined reserves of the Sullivan, Bluebell, and H.B. mines in 1966 totalled 71.6 million tons of ore containing 7.9 million tons of lead and zinc.

Bluebell Mine. The Bluebell mine, at the east side of Kootenay Lake in southern British Columbia, deserves mention because it has been worked longer than any other in Canada. An old excavation on the deposit is believed to be the place from which Indians obtained lead for making ammunition after contacts with early traders. The deposit was discovered, or re-discovered, in 1882 at about the time that placer mining in the region was giving way to lode prospecting and the Canadian Pacific Railway, to be completed through the western mountains in 1885, was going to make lode mining more attractive. Production from the Bluebell was begun in 1895 and has been continued inter-

mittently. Cominco acquired the property in 1927 and later built a concentrator having a daily capacity of 500 tons, which has now been increased to 700 tons.

Irregular orebodies containing galena, sphalerite, and other sulphide minerals follow fractures and bedding planes in limestone. Sills of pegmatite or coarse granite generally occur just below the hanging-walls of the deposits and may have been barriers to mineralizing solutions. In 1927 the grade of ore was reportedly 8.2 per cent zinc and 6.5 per cent lead. More recently such figures have been combined with those for the Sullivan and other mines owned by the same company.

Outlook. Large reserves of lead and associated metals are available in known deposits in various parts of Canada, and there were signs of oversupply in 1968, but the long-term demand for the metal will probably cause attractive new discoveries to be of interest. Present indications are that such deposits will probably be combinations of lead with other base metals, or silver, and that they are most likely to be found in the Cordilleran and Appalachian regions and in the part of the Interior Plains flanking the Cordillera. The scarcity of outcrops in the latter region restricts it especially to advanced methods of prospecting. The prices for lead declined from about 15.5 to 14 cents per pound during 1966 and from 14 to 13 cents in May 1968.

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LIME AND LIMESTONE

Limestone, which is essentially calcium carbonate, has a great variety of uses, perhaps more than those of any other rock. The main uses are in the manufacture of various chemicals, as filler in such products as paint, tile, and linoleum, as crushed limestone used in the manufacture of cement and for conditioning agricultural soils, and as building stone. In 1966 production of quicklime and hydrated lime was valued at nearly $20 million, and limestone used for other purposes, including building stone, was valued at nearly $74 million. Adequate supplies of limestone are available in many of the main consuming areas, but suitable deposits in areas where this is not so would probably be worth the attention of prospectors.

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LITHIUM

Lithium has various uses and the demand for it may increase. Lithium compounds are used mainly in ceramics and lubricating greases. Lithium metal is used in lightweight alloys. One isotope is reported to be a constituent of hydrogen bombs and it has potential use as a heat-transferer in fission nuclear reactors. Lithium hydride is a potential rocket fuel.

Until the recent discovery of large brine deposits in United States, which have reduced interest in Canadian prospecting possibilities, the principal sources of lithium were spodumene (lithium aluminum silicate), lepidolite (a lithium-bearing mica), and amblygonite (aluminum–lithium fluo-phosphate). These minerals occur in certain granite pegmatites, the chief production being in United States, Africa, and Canada. Most Canadian occurrences have been found in Superior and Slave Provinces, and the remainder in the Cordilleran and Appalachian regions. Small amounts of lepidolite and amblygonite were mined several years ago northeast of Winnipeg and east of Yellowknife, but significant production began at the Quebec Lithium mine near Val d'Or in 1956, which remains the only producer. It is worked on a series of parallel pegmatite dykes containing abundant spodumene. Ore reserves were reported to exceed 20 million tons averaging 1.15 per cent Li_2O_3 in 1966; total Canadian production of lithia (lithium oxide) in 1967 was 28,000 pounds valued at $565,000.

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MAGNESITE AND BRUCITE

Magnesia (magnesium oxide) is used extensively in the manufacture of refractory materials such as furnace linings, in the pulp and paper industry, and for various chemical processes. Production in 1967, valued at more than $3 million, was obtained from magnesite–dolomite rock at Kilmar, Quebec, and from limestone containing the mineral

brucite at Wakefield, Quebec. The latter operation has since ended. Magnesite and other magnesium minerals, if in suitable and well-placed deposits, would probably be in demand, but they are difficult to recognize. Most known occurrences are in belts of crystalline limestone in Grenville Province, but others have been found in various parts of Canada.

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MAGNESIUM

The main use of magnesium is as an additive in aluminum alloys. It is also used in anodes, structural applications, and die-casting. Magnesium is obtained from brines, seawater, and dolomite. Canadian production is from dolomite of unusual purity, in Ontario.

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MANGANESE

Manganese is an important metal used mainly in the manufacture of steel, about 12 pounds being used for every ton of steel produced. The other principal use is in making dry batteries.

Small amounts of 'bog' manganese ore have been produced at times in the Appalachian and Cordilleran regions, but none is produced in Canada. Workable deposits of manganese would undoubtedly be attractive, but geological studies and considerable prospecting have not disclosed any, although a prospect in New Brunswick has been explored.

The most important manganese minerals are pyrolusite (manganese oxide), psilomelane (hydrous manganese manganite) and manganite (hydrous manganese oxide). Most commercial deposits are a mixture of all three minerals, together with varying amounts of sand or clay, iron oxide, and barite. Wad or bog manganese is an earthy substance formed by precipitation from surface waters that have passed through rocks containing manganese. It commonly occurs as basin-shaped deposits a few feet deep or as small benches on gently sloping hillsides. Many such occurrences have been found in Canada, especially in the Maritime Provinces, Manitoba, and British Columbia, but their grade is variable and of low average.

Manganese minerals are also found in Canada in limestone of Carboniferous age, in red shale, conglomerate, granite and sandstone, the commonest occurrence of this kind being replacements in limestone. They generally consist of irregular deposits of manganese oxide that follow the bedding of the limestone and often branch into pipes and veins. Overlying many of these deposits is soil, gravel, or residual clay as much as 20 feet deep in which occur nodules and larger masses of manganese minerals. Less common occurrences are veins and breccia fillings composed of manganese minerals.

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MERCURY

Mercury (quicksilver) is widely used, especially in wartime for making detonators. Almost all mercury is produced from cinnabar (mercury sulphide), easily recognized by its bright red colour.* Most deposits were formed at fairly shallow depths, in sedimentary rocks in regions of major fracturing or faulting and volcanic activity of Tertiary or later age; therefore virtually all Canadian discoveries are in the interior of British Columbia. Almost all the mercury produced in the Commonwealth during World War II was derived from the Pinchi Lake deposit, found and reported by a party of the Geological Survey of Canada doing routine mapping. The value of this output was large but the mine was closed in 1944 when the price of mercury fell and cheaper supplies from Italy and Spain became available. Smaller production was obtained in British Columbia in 1943–44 from the Takla mine which, like the Pinchi Lake, is associated with the Pinchi fault zone. Production was resumed at the Pinchi Lake mine in 1968 after large expenditure on underground development and a new treatment plant.

Interest in prospecting for mercury has revived during the last few years because of increased price and the desirability of finding a large deposit of fairly high grade. A point to be remembered when one pans streams in the Cordillera is that prospectors are sometimes misled by the occurrence of small beads of mercury that was commonly used for collecting placer gold and sometimes allowed to escape. Almost every Cordilleran stream was mined or tested during gold-rush days.

* Cinnabar in weathered outcrops may be brownish.

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METEORITES

Meteorites are iron or stony masses that have fallen upon the earth from interplanetary space. Although fairly rare, and not strictly within the realm of prospecting, these objects are of interest to prospectors because of the fascination they arouse and because they are saleable. They are an invaluable source of information to scientists and genuine finds will be purchased by the Geological Survey of Canada.

A *meteor* is a body falling from space that becomes incandescent from friction with the earth's atmosphere when entering it at tremendous speed. The common, so-called 'shooting stars' result from the entry of tiny particles that may be related to comets. Bright spectacular meteors, also called 'fireballs', result from the entry of larger bodies that are believed to have come from the breaking up of small planets or asteroids.

Most fireballs are reduced to dust before they reach the earth's surface but, if sufficiently large, some of the original mass survives and falls to earth as a *meteorite*. An important requirement for tracking down a meteorite is to have a sufficient number of good observations of the fireball made from points over a considerable area, which can be used to triangulate the path and determine the probable area of fall. Of particular importance are fireballs visible in daylight and those that produce sounds. These sounds are generally in the nature of detonations or rumblings and will probably be heard several minutes after the fireball has disappeared.

Meteorites are of three main kinds called iron, stone, and stony-iron. Iron meteorites consist essentially of metallic nickel–iron alloy and hence are most easily recognized because of their unusual weight and magnetic property. Stony meteorites contain mainly silicate minerals similar to certain rocks of the earth but may also contain nickel–iron particles. Stony-iron meteorites are mixtures of the other two types.

Generally, meteorites are difficult to recognize except in places where ordinary rocks are not likely to be found, such as on snow or ice or soil devoid of rocks. Newly fallen meteorites have a distinctive, thin, dull black crust (called the fusion crust), which formed during the passage through the atmosphere. Shallow, rounded depressions on the surface are also characteristic, especially on iron meteorites. Meteorites range in size from small fragments to masses weighing several tons. It is known that very large meteorites can form extensive craters, although in many large craters believed to be of meteoritic origin, no meteorite is found because it apparently disintegrated explosively when it struck.

The Geological Survey of Canada will pay $100 or more for the first specimen of any Canadian meteorite that is acquired for the National Meteorite Collection; a small piece of any suspected meteorite should be sent there for identification. It is important, however, not to damage a meteorite unnecessarily as this will reduce its scientific as well as its monetary value. Anyone sighting a bright fireball can aid in the possible recovery of a meteorite by reporting it to the Meteor Centre, National Research Council, Ottawa.

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MICA

Although mica is used in relatively small quantities, mainly in ground form, it is an important commodity used in paints and plastics, and in electrical appliances because it splits into thin, insulating sheets. The name is applied to a family of silicate minerals with different compositions and properties. Muscovite, the clear mica, is the most important type, and phlogopite, sometimes called amber mica, is also used. Mica is a common constituent of pegmatite dykes, but only those containing muscovite in unusual size, quantity, and quality are likely to be important. Canadian production, chiefly from several little operations in Quebec and Ontario, has been small. Under present economic conditions almost all mica used in Canada is imported, as it is difficult to compete with inexpensive, high-quality mica from other countries. Phlogopite deposits that would otherwise be suitable are not being worked, and muscovite deposits are not likely to be profitable except during periods of special demands and high prices. If interested at all, prospectors should concern themselves only with muscovite in sheets 6 inches or more in size, which appear to be without flaws. Some muscovite appears to be dark brown or black where in thick crystals, but individual sheets are transparent. Particulars regarding grading are included in the report by Hoadley listed below.

Vermiculite, which resembles mica, is a black, brown, or green mineral sometimes formed by alteration of mica. It expands remarkably under strong heat, which makes it useful as a heat insulator. All vermiculite used in Canada is imported. There seem to be few domestic occurrences of

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MOLYBDENUM

Large quantities of molybdenum are used in industry, 90 per cent being for the production of hard and corrosion resistant steels. For many years the market was dominated by the large Climax property in Colorado, although a good deal of molybdenum was produced in Canada during both World Wars, when demand and prices were high, mainly from small operations on pegmatite deposits. During the last few years improvements in techniques and increased economic activity have caused much greater demand. Canadian production has increased steadily during the last six years. In 1966 four mines were producing in Quebec and four in British Columbia. Canadian output of molybdenum concentrates and compounds in 1968 exceeded 22 million pounds valued at nearly $38 million. Canada is the second largest producer in the western world, after United States. The shortage that developed in world markets in 1963 was overcome in 1968, but the long-term outlet for important new discoveries is regarded as favourable because oversupply of a non-staple metal generally leads to the perfection of new applications for it, and thus to another cycle of increased demand.

The only molybdenum mineral mined commercially in any country is molybdenite (molybdenum sulphide), which is common as insignificant occurrences. The most important deposits known are disseminated in quartz veins and stockworks in plutonic rocks ranging in composition from granite to granodiorite, and commonly occurring near the margins and roofs of such masses. Other important production is as a by-product from certain copper orebodies, mainly of the porphyry–copper type. The great Climax deposit comprises quartz stockworks around a core of barren silicified granitic rocks. The principal deposits near Val d'Or, Quebec, are veins and lenses of quartz and material representing a transition between pegmatite and vein-quartz in the marginal zones of granite and granodiorite bodies. Average grade is about 0.25 per cent MoS_2. The largest Canadian mine, near Endako, B.C., which has a capacity of 15,000 tons of ore daily, is operated on quartz veins and silicified zones in fractures in granite. The ore averages about 0.2 per cent MoS_2. It was staked in 1927 following a discovery of molybdenite in float. The ore deposit at the Boss Mountain mine in British Columbia is a breccia zone in quartz diorite and related rocks. Grade of ore varies upward from 0.3 per cent MoS_2.

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NICKEL

For many years Canada has been the world's chief producer of nickel, the importance of which as an additive in steels, in coinage, and in plating is too well known to require further mention. It was the principal metal in value of production in Canada in 1965, but was exceeded by the value of copper production in 1967. Production in 1965 totalled 260,000 tons valued at $430 million, which was about one-fifth of the total value of metals in Canada in that year. Nickel is mined chiefly in the Sudbury district of Ontario and in the Thompson and Lynn Lake areas of Manitoba. Smaller amounts are mined in Quebec and British Columbia. In 1967 about 76 per cent of Canadian production was from Sudbury mines and 22 per cent from mines at Thompson and Lynn Lake.

History

Nickel is of such importance to Canada's economy that it may be interesting to mention the origin of the name. In the eighteenth century, miners in Saxony found that certain ores of copper, when treated by the usual smelting methods, yielded, instead of the expected red metal, a light-coloured metal that was difficult for them to work with, and to which they gave the name of 'kupfer-nickel' or 'Old Nick's copper'. In 1751 the Swedish chemist, Cronstedt, succeeded in isolating the mysterious element, which he named 'nickel' after the Saxon nickname for the metal.

About 1877 a company was organized to acquire nickel and copper discoveries near Orford in the Eastern Townships of Quebec. Difficulty in treating the nickel ore caused

the company to devote most of its attention to copper mining. In the following year the company was reorganized as the Orford Copper and Sulphur Company, and a refinery was built in New Jersey, U.S.A. The manager of the refinery, R. M. Thompson, discovered a practical method of separating nickel and copper from the smelter product by what was called the Orford process.

In 1883 a blacksmith named Flanagan, working on the construction of the Canadian Pacific Railway near the village of Sudbury, found copper sulphides along the right-of-way. He did not record a claim and others staked the ground a few months later. Several discoveries that later became important were found in 1884 by prospectors who were searching for gossans. In 1886 the Canadian Copper Company, forerunner of the International Nickel Company, was incorporated to acquire several properties. Mining began at the Copper Cliff mine in that year, and the construction of the first smelter was completed in 1888. The product from the smelter was sent to the Orford refinery in New Jersey, but the presence of nickel caused trouble and led to the commercial development of the Orford process, which made the separation of the metals economically possible. Much research during the years that followed has resulted in greatly improved treatment methods and in the development of new uses for nickel, mainly in special nickel–steel alloys that are now indispensable in peace and war.

The history of the discovery of the Falconbridge mine is interesting because it is connected with early successful applications of geophysical exploration and diamond drilling for base metal mines. In 1901 the late Thomas A. Edison made a dip-needle survey in Falconbridge township because he needed nickel for making a storage battery he had invented. Geological mapping had shown the vicinity to be favourable in a general way. He obtained indications that were tested by sinking a shaft, but the attempt was abandoned because quicksand was encountered. Diamond drilling later revealed an orebody at this place. The property was acquired by the present company, which completed a smelter to treat the ore in 1930.

Thirty-four mines have been or are being operated, mainly by The International Nickel Company of Canada, Limited and Falconbridge Nickel Mines, Limited in the Sudbury area. There were sixteen in 1966, and others were being prepared for production in these companies. Kidd Copper Mines Limited began operation of a mine near Worthington in the same year.

The first large nickel mine to be brought to production in Canada outside the Sudbury district was the Lynn Lake mine in northern Manitoba. The deposit was found in 1941 as the result of a systematic prospecting program that had been carried on in the area by Sherritt Gordon Mines, Limited for four years. The first discovery, by a company prospector, was followed by geophysical surveys and drilling. Demonstration that a substantial operation was possible came at about the same time as the exhaustion of the Sherritt Gordon copper–zinc mine at Sherridon, Manitoba. The company transported nearly all the buildings and the mining and milling plant from Sherridon to Lynn Lake, a distance of about 150 miles. Buildings were placed on large sleighs and hauled by tractors during the winter over frozen lakes and muskegs, and winter roads were cleared where necessary. A branch railway line 147 miles long was completed from Flin Flon by the end of 1952. Underground development and a large concentrator were completed at the mine, and a refinery using a new process was built at Fort Saskatchewan near Edmonton, Alberta, to take advantage of supplies of natural gas. Full-scale operation of the mine and concentrator began late in 1953; the first nickel concentrates were produced in November, and were treated at the Fort Saskatchewan refinery in July, 1954.

The Thompson mine, 400 miles north of Winnipeg, was found by International Nickel Company of Canada and brought to production at the end of 1960, after a long systematic search for nickel outside the Sudbury area. The company began prospecting in Manitoba in 1946 and concentrated on the general Moak Lake–Setting Lake area a little north of the mid-point of the Hudson Bay railway. A belt about 200 miles long and 20 miles wide, considered geologically favourable, was subjected to additional geological and photogeological studies, and aeromagnetic surveys followed by airborne electromagnetic surveys. The general anomalies were then covered by ground geophysical surveys, diamond drilling of anomalies, and geological studies of the surface and drill-cores. In 1949 an independent prospector found an occurrence of nickel in the belt, by conventional means. This lent encouragement to the new project but was not considered a main factor in its successful outcome. The first large deposit found by drilling, at Mystery Lake, was followed in 1952 by a more encouraging discovery at Moak Lake. In 1956, drilling of what appeared to be anomalies of secondary importance resulted in discovery of the more commercial Thompson deposit. Development of this deposit required large expenditures on testing and on construction of a town, concentrator, smelter, and refinery. The company reported that it spent $10 million on the first phase of the program; that, from the beginning of prospecting in 1946 until drilling of the Thompson deposit revealed sufficient ore to justify production, an additional $15 million was spent on further exploration in the area; and that capital expenditures up to 1956 totalled more than $140 million. In the same area the company prepared the Birchtree, Soab, and Pipe Lake mines for production in 1968 and 1969.

Several smaller mines are producing or have produced nickel in various parts of Canada. The Giant Mascot mine in British Columbia was found in 1923 and has been operated intermittently under various names. The Gordon Lake mine in western Ontario was found in 1942 and became productive in 1962; the Lorraine mine near Belleterre, Quebec, is believed to have been discovered about 1933 and became productive in 1962; and the Marbridge mine ships a nickel–copper concentrate from northwestern Quebec. The North Rankin mine at Rankin Inlet, Hudson Bay, was found in 1931 and was productive from 1957 to 1962. All are believed to have been discovered by conventional prospecting.

Minerals

The principal nickel mineral is pentlandite (iron nickel sulphide); nickeliferous pyrrhotite is commonly associated with it. Among minor primary minerals are niccolite (nickel arsenide), millerite (approximately nickel sulphide), and skutterudite (cobalt–nickel arsenide). Nickel minerals are commonly associated with those of copper and cobalt. The near-surface parts of some nickel deposits contain small amounts of apple-green secondary minerals such as annabergite; if present these may be useful guides in prospecting.

Deposits

The typical orebodies of the Sudbury district are large irregularly shaped bodies containing massive and disseminated sulphide minerals, mainly pyrrhotite, with smaller but important amounts of chalcopyrite and pentlandite. Valuable amounts of gold, platinum, and other metals are also present. Several years ago the average grade of the ores was about 3.5 per cent nickel and 2 per cent copper, but in recent years with operations on an expanded scale ore of lower grade has been treated. This is reported to average roughly 1 per cent nickel and the same in copper. The orebodies occur at and near a body of mafic intrusive rock that was described in 1897 by T. L. Walker as grading from a more basic type called norite to a more acid type called micropegmatite. A few years later A. P. Coleman mapped the region for the Ontario Department of Mines and showed that the intrusive is in the form of a large basin-shaped mass 37 miles long and 17 miles wide, with the micropegmatite towards the centre and the norite outermost, and that the orebodies are near the outside of the basin. This 'Sudbury Irruptive' is surrounded by granite and Huronian rocks and overlain in the centre by Precambrian sedimentary rocks. Coleman proposed the explanation that the two kinds of rock and the ore segregated by settling from a molten magma that was intruded in the form of a great sheet. Others have suggested that the two kinds of rock were intruded separately. Detailed investigations by company geologists between 1940 and 1950 showed that the ore commonly is closely associated with quartz diorite masses resembling dykes, which are probably younger than the norite. These geologists also showed that the orebodies are generally localized where fault and breccia zones cross the diorite and nearby rocks. Thus, the simple theory of magmatic segregation in place does not fit the evidence. It appears, rather, that the ore is the last, perhaps hydrothermal, phase of a long sequence of events that began with the intrusion of the basic sill-like mass and was followed by the diorite, after which faulting and brecciation occurred before the emplacement of the ore. Because of the importance of the deposits and their rather unique features, they receive much study, resulting in minor modifications of theories from time to time.

The deposits at and near Thompson are in the transitional zone between Superior and Churchill Provinces of the Canadian Shield, where the rocks strike northeast in constrast with the easterly trends in the Superior and the irregular northeasterly trends in the Churchill. They are a few miles east of a prominent zone of faulting. The ore consists mainly of masses, lenses, and veinlets of pyrrhotite, pentlandite, and pyrite in schist and altered sedimentary rocks, and as stringers, veinlets, and disseminations in serpentinized peridotite. Nearly all the peridotite in the area is in linear zones in metamorphosed sedimentary and volcanic rocks enclosed in gneisses. In 1960 ore reserves at Thompson were reported to be 25 million tons containing 2.97 per cent combined nickel and copper. The copper content is lower than that of the Sudbury ores, the nickel–copper ratios being greater than 15 to 1 but some of the other deposits of the Thompson area are understood to contain more copper than the Thompson deposit itself.

The Gordon Lake deposit, which lies chiefly beneath a lake, is in a shear-zone intruded by lenses of ultramafic rocks carrying stringers and disseminations of pyrrhotite, pentlandite, and chalcopyrite. The ore at Marbridge is in a belt of altered volcanic, sedimentary rocks and peridotite apparently squeezed between two granitic batholiths. The peridotite is cut by a shear-zone containing massive and disseminated pyrrhotite and pentlandite. The Lorraine orebody is in a belt consisting mainly of altered volcanic rocks intruded by various plutonic rocks including peridotite. The deposit is in a shear zone containing chalcopyrite, pyrite, pyrrhotite, and pentlandite.

The Giant Mascot deposit is in a belt of altered late Paleozoic strata and Mesozoic plutonic rocks including a stock-like body of ultrabasic rocks in which occur masses and disseminations of pyrrhotite, pentlandite, and chalcopyrite.

The North Rankin deposit was at the east end of a belt of Archean sedimentary and volcanic rocks extending in a general way from Lake Athabasca to Rankin Inlet. J.B. Tyrrell of the Geological Survey of Canada found volcanic rocks carrying chalcopyrite at Rankin Inlet about 1893, and his report led prospectors to discover nickel in pyrrhotite in a pyroxenite sill there in 1928.

Inco is preparing its Shebandowan property west of Port Arthur for production in 1971. This deposit, which the company has held for many years, and tested at times, is in a shear zone in peridotite. The zone contains pyrite, chalcopyrite, pyrrhotite, and polydymite (nickel sulphide).

Outlook

Demand for nickel has been strong in recent years. Although Canadian companies have large reserves of ore, the number of uses for nickel indicates large, long-term demands. World requirements have stimulated increased interest in the development of lateritic ores in other countries. Even if these should replace some Canadian export markets, additional economic discoveries in this country are expected to be attractive; although the present world shortage is expected to be relieved by the end of 1972.

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NIOBIUM(COLUMBIUM) AND TANTALUM

Niobium and tantalum are two closely related metals that commonly occur together in the same minerals and are separable only by complicated chemical procedures. Niobium is the official name for the element more commonly known in Canada and the United States as columbium. Niobium is particularly important for making special corrosion-resistant and heat-resistant alloys in wide use today. Tantalum is used mainly for alloys having high resistance to wear and corrosion, and also in special kinds of optical glass.

The principal source of niobium and tantalum was formerly a mixture of two minerals, columbite and tantalite, found in pegmatites and in placers derived from weathering of granites. Large amounts of niobium were obtained chiefly from cassiterite–columbite placers and decomposed columbite-bearing granite in Nigeria.

Niobium and tantalum are also produced from the pyrochlore–microlite series of minerals, a chemically complex group of which the most niobium-rich is called pyrochlore and the most tantalum-rich, microlite. These occur mainly in carbonatites and other alkaline-rock complexes characterized by roughly circular or elliptical shapes and low silica and high sodium contents.

Niobium and tantalum minerals are commonly accompanied by radioactive minerals and, largely as a result of prospecting for uranium, a belt of alkaline-rock complexes is now known to extend from Oka, Quebec to near Chapleau, Ontario. At least one deposit of this general type, but lacking apparent circular shape, has been found in British Columbia. Several pegmatitic deposits have been found in the Yellowknife–Beaulieu area, Northwest Territories, some of various kinds are known in other parts of the Canadian Shield, and a few are reported from the Cordilleran and Appalachian regions. The most promising types for prospecting are alkaline-rock complexes and placers.

Production was begun at the St. Lawrence columbium deposit at Oka in 1961 and has been increased each year. Production in 1967 was more than 2 million pounds of niobium concentrate valued at $2,627,000. Ore is reported to average 0.4 per cent niobium oxide. This mine is one of two producers of niobium concentrate in the world, the other being in Brazil. Several other deposits of this general type have been tested in the Oka area.

Suggestions for Additional Reading

Rowe, R.B.
1958: Niobium (Columbium) deposits of Canada; *Geol. Surv. Can.*, Econ. Geol. Ser. No. 18.
Wigle, G.P.
Niobium (Columbium) and tantalum; *Min. Res. Br.*, Ann. Rev.

PHOSPHATE

Large amounts of phosphate rock and other phosphatic materials are imported into Canada for the production of fertilizers and other phosphorus products. Almost all the phosphatic industrial products are consumed in Canada and a very large part of the phosphatic fertilizers are used here although in recent years Canadian phosphate fertilizer production has been exported, mainly to the United States. The production of phosphate fertilizer is attractive in Canada because sulphuric acid from low cost smelter gases or elemental sulphur from 'sour' natural gas in western Canada is available to process imported phosphate rock.

From 1850 to 1900 phosphate was obtained from apatite in pegmatites in Quebec and Ontario. This source was replaced by cheaper raw materials brought from United States. Many occurrences of phosphate rock have been found and tested in the Canadian Rocky Mountains. These have not proved to be of qualities competitive with American sources, but better ones might be found, particularly in the Cordilleran region. Also, apatite occurrences associated with alkaline rock complexes in the Canadian Shield are being investigated.

Suggestions for Additional Reading

Bartley, C.M.
Phosphate; *Min. Proc. Div.*, Ann. Rev.

PIGMENTS

Many different minerals and compounds obtained from them were formerly used for colouring various products or in making paints. Synthetic pigments have largely replaced these. Relatively small amounts of iron oxides are mined in the St. Lawrence Lowland of Quebec for use in purifying manufactured illuminating gas, for pigments in paints, and as polishes. These deposits have been worked since 1886, and appear adequate for all demands. Oxides of titanium, lead, and zinc are used in the manufacture of paints, and are discussed in other sections.

Suggestions for Additional Reading

Stonehouse, D.H.
Mineral pigments and fillers; *Min. Proc. Div.*, Ann. Rev.

PLATINUM

Platinum and other metals of the platinum group — palladium, rhodium, ruthenium, iridium, and osmium — are produced in fairly large quantities as by-products of Canada's nickel mines. In 1967 this production amounted to about 403,000 ounces valued at $34½ million. For some time Canada has been a leading producer of these metals, and is the third largest producer after the Soviet Union and the Republic of South Africa.

In the Sudbury ores platinum occurs in the mineral sperrylite, which is scattered sparsely among the sulphide minerals. Small amounts of native platinum have been produced from the Cordilleran region as a by-product of gold placers.

Unique uses for the platinum metals indicates that strong demand for them should continue. Prospecting will probably be mainly for nickeliferous lodes rather than directly for platinum. Possibilities also exist for discovery of placers that could be worked for platinum or other metals of the group, particularly in the Western Cordillera.

Suggestions for Additional Reading

Killin, A.F.
Platinum metals; *Min. Res. Br.*, Ann. Rev.

O'Neill, J.J., and Gunning, H.C.
1933: Platinum and allied metal deposits of Canada; *Geol. Surv. Can.*, Econ. Geol. Ser. No. 13.
A comprehensive summary up to 1933.

POTASH

Since the mining of potash was begun in Saskatchewan in 1958 that province has become one of the world's leading producers of this commodity, which is used mainly in the manufacture of fertilizers. Only a brief note is included here, however, because of the extensive reserves proven or probably present beneath a large part of the Interior Plains. These reserves indicate that expansion of this industry for the future will be based on further testing of known possibilities rather than on initial prospecting.

In 1943 routine examination of cuttings from a well drilled for oil in Saskatchewan showed the presence of sylvite (potassium chloride) in strata about 7,000 feet below the surface. Later drilling disclosed the potash formation at shallower depths and showed that a large area in Saskatchewan and smaller areas in Alberta and Manitoba were underlain by the Prairie Evaporite Formation of the Elk Point Group, of Devonian age, containing halite (sodium chloride), sylvite, and carnallite, a more complex potash mineral. Oil companies and United States potash companies began further investigations, including geophysical logging of some re-opened wells, and other companies entered the field later, as engineering studies and increasing demands for potash made operations feasible. Production has been uninterrupted since 1962, after initial mining difficulties were overcome.

Four mines were in production in 1967 and six more were being prepared. Most mining is by underground excavations from shafts, but one company operates the world's first potash 'solution mine'. In the latter method, two concentric 'tubes' are placed in a well, water is forced down one and circulated in the desired strata, where sylvite is dissolved. The resultant is pumped up the other part of the tubular system, and evaporated in a plant on the surface.

Total production in 1967 totalled 2.6 million tons of potassium oxide (K_2O) equivalent, having a value of more than $77 million.

Suggestions for Additional Reading

Bartley, C.M.
Potash; *Min. Proc. Div.*, Ann. Rev.

Harding, S.R.L., and Gorrell, H.A.
1967: Distribution of the Saskatchewan potash beds; *Trans. Can. Inst. Mining Met.*, vol. 70, pp. 174–179.

Strain, H.D.
1966: The Saskatchewan potash industry; *Bull. Can. Inst. Mining Met.*, May, pp. 557–559.

RADIUM

Radium exists in minute quantities in all uranium-bearing minerals, roughly as one part of radium to 3,000,000 parts of uranium. There are no separate radium minerals. Uranium minerals were formerly mined almost entirely for their radium content, but later uranium became the prime object and adequate supplies of radium were obtained from certain uranium operations. Radium had important medical and industrial uses, but for many of these it is now replaced by cheaper and more suitable radioactive substances (isotopes) such as radioactive cobalt, produced in atomic reactors. Production of radium at the Eldorado refinery at Port Hope was ended in 1953 owing to lack of demand.

RARE EARTHS

The so-called 'rare earths' are a series of fifteen elements having closely related chemical and physical properties. The name 'rare earths', applied many years ago, is rather

inappropriate, and the name 'lanthanons' has been proposed for rare-earth oxides. The elements are not particularly rare, although they are usually dispersed in small and unimportant quantities. They were called earths because their oxides are earthy, but they are actually metals. The element 'yttrium' is customarily discussed with the rare earths because some of its properties are related to them. The elements are grouped in various ways by authorities, a common method being as follows (with the exception of yttrium the elements are listed in the order of increasing atomic weights):

Cerium Group or Light Rare Earths	Lanthanum Cerium Praseodymium Neodymium Promethium Samarium Europium	Yttrium Group or Heavy Rare Earths	Gadolinium Terbium Dysprosium Holmium Erbium Thulium Ytterbium Lutetium Yttrium

The cerium group is used in the manufacture of carbon-arc electrodes, special alloys, and for other uses, and some of the heavier rare earths and yttrium are reported to be in demand for special uses. The cerium group is obtained from monazite concentrates from beach sands and placers in Brazil, Ceylon, India, the United States, and other countries, from a monazite-bearing vein in Africa, and now mainly from bastnaesite (fluo-carbonate of rare earths, etc.) produced in United States from a body of carbonate rock. The cerium group is also present in such minerals as allanite and pyrochlore. This group is said to be in plentiful supply in world markets. Occurrences of monazite and allanite are fairly abundant in Canada and deposits containing bastnaesite have been found at the Rexspar property, in British Columbia.

Gadolinium and yttrium appear to be particularly in demand, the latter having a newly developed use in connection with colour television. One or more members of the group occur in xenotime, gadolinite, fergusonite, euxenite, samarskite, and a few other minerals, but these are generally only minor accessory minerals in pegmatites and other deposits. As most are uranium-bearing as well, many are mentioned in the section and references for uranium.

Several of the elements of both groups are minor constituents of the Elliot Lake uranium ores and are concentrated in a plant. Yttrium predominates in the mixture of rare-earth elements in the concentrate and payment is based solely on the yttrium content. The individual elements are not separated in this country.

Problems in prospecting for rare earths include the following: the minerals are difficult to identify except by laboratory methods; specimens for study are hard to obtain (they cannot be obtained in sufficient quantity for sale by the Geological Survey of Canada); workable or by-product deposits would probably need to contain a fair amount of the appropriate mineral or minerals; chemical analyses are costly and difficult, and usually report only total rare earths and cerium (*see* Chapter 14); semi-quantitative spectrographic or other kinds of analyses can probably be obtained at less cost from some laboratories, but these generally report only certain of the elements, particularly cerium, lanthanum, yttrium, and ytterbium.

Suggestions for Additional Reading

Jackson, W.H.
Rare-Earth elements; *Min. Res. Br.*, Ann. Rev.

Rose, E.R.
1960: Rare-Earths of the Grenville Sub-province, Ontario and Quebec; *Geol. Surv. Can.*, Paper 59-10.
1969: A progress report on experiments with chemical field tests for the detection of the rare-earth elements and yttrium; *Geol. Surv. Can.*, Paper 69-15.

SALT

Large quantities of salt (sodium chloride) are produced and used in Canada, mainly as a source of sodium and chlorine for chemical industries. The next largest use is for removing or controlling ice and snow on highways and streets. Smaller quantities of refined salt are used as table salt and for seasoning in the processing of foods. Production in 1966 was more than 4 million tons valued at more than $23 million. This was obtained mainly as rock salt from underground mines in southern Ontario and in Nova Scotia. Salt is obtained from the evaporation of brines in Nova Scotia, Ontario, and the Prairie Provinces, and as a by-product of potash mining. For most uses salt is not sufficiently valuable to warrant shipping over long distances. For this reason salt valued at more than $2 million was imported for use in certain parts of the country. This indicates that there should be demands for suitable deposits near main centres of population and industry not now adequately served by local supplies. Canadian salt is obtained from evaporite deposits in strata of Paleozoic and Mesozoic ages.

Suggestions for Additional Reading

Cole, L.H.
1930: The salt industry of Canada; *Mines Branch,* Rept. 716.

Hewitt, D.F.
1962: Salt in Ontario; *Ont. Dept. Mines*, Ind. Min. Rept. No. 6.

Stonehouse, D.H.
Salt; *Min. Proc. Div.*, Ann. Rev.

SAND AND GRAVEL

Sand and gravel of suitable kinds are used so extensively for making concrete and in various other ways related to construction that they form the largest volume of the Canadian mineral industry and account for much of its total value. Production in 1967 amounted to nearly 222 million tons worth more than $158 million. Suitable deposits near centres of population and construction projects will be required increasingly as this country is developed, but specifications are usually exacting. Sources of natural products are becoming depleted because of the increasing demands for materials in the rapidly growing industrial areas.

Beneficiation of sub-quality natural aggregates provides a limited quantity of quality materials; however, recourse to the development of manufactured aggregates from bedrock is inevitable.

Suggestions for Additional Reading

Hanes, F.E.
Sand, gravel and crushed stone; *Min. Proc. Div.*, Ann. Rev.

Hewitt, D.F., and Karrow, P.F.
1963: Sand and gravel in southern Ontario; *Ont. Dept. Mines,* Ind. Min. Rept. No. 11.

Picher, R.H.
1935: Road gravels in Quebec; *Mines Branch*, Rept. No. 751.

SELENIUM

Canada is one of the leading producers of selenium, which is used mainly in the electrical and electronics industries. The demand is reported to be increasing slowly. The metal is recovered as a by-product of the refining of copper and does not seem likely to be found in deposits workable for selenium alone. Production in 1967 was about 750,000 pounds valued at about $3½ million.

Suggestions for Additional Reading

Killin, A.F.
Selenium and tellurium; *Min. Res. Br.*, Ann. Rev.

SILICA

Silica (silicon dioxide) commonly occurs as the mineral quartz in sand, sandstone, quartzite, and vein quartz deposits. Although occurrences of silica are widespread, only those deposits of high purity are of commercial interest.

Domestic production of silica is confined to Ontario, Quebec, Manitoba, Saskatchewan, and British Columbia, and consists mainly of crushed quartzite and sandstone, and sand for use as metallurgical flux. The remainder consists of lump silica for use in silicon and ferrosilicon manufacture and in the production of elemental phosphorus, and silica sand for glass manufacture, silicon carbide production, foundry use, and for other purposes.

Although the annual production of silica sand in Canada has gradually increased over the last decade, the two current domestic producers (one in southern Quebec, the other in Manitoba) today supply only 25 to 30 per cent of the Canadian market. The Quebec producer supplies perhaps 60 per cent of the Quebec silica sand market. The balance of this market is supplied from the United States. The Quebec producer is unable to compete with imported sand in Ontario because of higher processing costs and freight rates, so this market is entirely supplied by producers in northeastern United States. The Manitoba producer supplies a large part of the silica sand market in western Canada but is unable to compete with imported sand in the southern Ontario market or in British Columbia. The latter market is largely supplied by imports from the United States.

More than one million tons of silica sand are imported annually from the United States to supply domestic requirements such as the manufacture of glass and artificial abrasives and for foundry purposes. Considerable demand exists for silica deposits, particularly sand, friable sandstone, or quartzite of high quality. Such occurrences in southern Quebec or southern Ontario, the principal market area, would be worthy of detailed study and evaluation.

Suggestions for Additional Reading

Collings, R.K.
Silica; *Min. Proc. Div.*, Ann. Rev.

SILVER

Canada is among the four leading silver-producing countries of the non-communist world; our mine output in 1967 was 36,426,000 ounces valued at $63 million. World consumption and prices have risen substantially in recent years. The price rose sharply in May 1967 and was $1.40 to $2.34 per ounce for the remainder of that year. The uses of silver seem to indicate that future demands will continue to be strong, but the future price is more difficult to assess. Most silver is now used for silverware, silverplate, photographic films, alloys, and other industrial purposes. Ontario is the leading silver-producing province, followed by British Columbia, Quebec, Yukon Territory, New Brunswick, Northwest Territories, and Newfoundland.

In 1967 co-product and by-product production of silver from lead, zinc, or copper deposits accounted for more than 85 per cent of Canadian production of silver (a large new producer is the Kidd Creek zinc–copper–silver deposit near Timmins, Ontario); more than 13 per cent came from silver–cobalt deposits, and the remainder was obtained from the refining of lode and placer gold. Only the silver–cobalt deposits are discussed further here because the others are covered at least in a general way by the sections on lead, zinc, and copper. It should be noted, however, that many gold–silver and lead–silver deposits in British Columbia, particularly in the Portland Canal and Slocan districts and in the Keno district of Yukon Territory, are rich sources of silver.

The silver ores of Cobalt, Ontario, discovered in 1903 during construction of a railroad, together with similar ore from nearby areas developed soon afterwards, formed what was then the main silver producing area of the world. In a period of 33 years it yielded silver valued at more than $230 million. Low silver prices and other difficulties during the Great Depression caused closure of the mines. Recent demands caused reopening of some mines, additional discoveries of ore at some properties, and some new properties based on recent discoveries. The Cobalt area is in Superior Province of the Canadian Shield. The principal rocks of the area are Keewatin metavolcanics and overlying Huronian metasediments of the Cobalt Group. Rocks of both groups are cut by a thick sill or sills of diabase. The deposits are veins of calcite and other carbonate minerals found mainly in the sediments but also in

the volcanics and the diabase. The veins contain native silver and various cobalt–nickel–arsenide minerals, including cobaltite and niccolite–smaltite, as well as argentite, arsenopyrite, and chalcopyrite.

It seems inevitable that prospecting specifically for silver in Canada will be overshadowed by that done for nonferrous metals in general, which may be accompanied by silver. Possibilities do exist, however, for discovering additional deposits of native silver or other minerals for which silver is the main interest. For such prospecting, one should learn to identify the secondary mineral *erythrite* (cobalt bloom) which is commonly a useful guide.

Suggestions for Additional Reading

Boyle, R.W.
1968: The geochemistry of silver and its deposits; *Geol. Surv. Can.*, Bull. 160.

George, J.G.
Silver; *Min. Res. Div.*, Ann. Rev.

Patterson, J.W.
1963: Silver in Canada; *Min. Res. Br.*, Mineral Survey 3.

Petruk, W.
1967: Ore deposits of the cobalt area; *Mines Branch*, Reprint Ser. R. S. 44.

SODIUM SULPHATE

The demand for sodium sulphate (salt cake) for use in the pulp and paper industry increases steadily. Canadian production, valued at more than $6 million in 1966, is obtained from the evaporation of brines in certain lakes in Saskatchewan. Sulphates in soil are dissolved by water from rain and melted snow and carried into closed drainage basins where they are concentrated by evaporation and chilling. Known reserves in Saskatchewan are estimated to contain more than 200 million tons of sodium sulphate, and smaller deposits are known in Alberta and British Columbia. The increasing demand and the fact that some sodium sulphate is imported suggests that additional, suitable, well-situated deposits would receive attention.

Suggestions for Additional Reading

Bartley, C.M.
Sodium sulphate; *Min. Proc. Div.*, Ann. Rev.

STONE

Crushed stone and building stone derived from rocks of various kinds are quarried in many parts of Canada; total production in 1967 according to preliminary figures of the Dominion Bureau of Statistics was nearly 84 million tons valued at more than $104 million. In some references crushed stone is described together with sand and gravel, but the value mentioned above is mainly that of crushed stone, which is used in large quantities for concrete aggregate, road construction, the manufacture of synthetic stone, and other well-known purposes.

Ordinary building stone is quarried for local use in many parts of Canada. Granite (in the trade sense, which includes many varieties of igneous rocks) accounts for most Canadian production, followed by limestone and sandstone. Attractive and especially suitable stone for decorating buildings and making monuments is quarried selectively to lesser extent in Canada, but much is imported. Crushed stone and ordinary building stones, being bulky commodities of relatively low unit values, are not usually shipped far from their source. As deposits become worked out or as new centres of population and construction develop, demands will probably be created for additional deposits. The industry, facing stiffer specifications and more artistic uses for these materials, is obliged to undertake more thorough investigation of potential deposits. Specifications from some of the following publications will be helpful.

Suggestions for Additional Reading

Carr, G.F.
1955: The granite industry of Canada; *Mines Branch*, Dept. of Mines and Technical Surveys, No. 846.

Goudge, M.F.
1933: Canadian limestones for building purposes; *Mines Branch*, Rept. No. 733.

Hanes, F.E.
Stone, building and ornamental; *Min. Proc. Div.*, Ann. Rev.

Hewitt, D.F.
1960: The limestone industries of Ontario; *Ont. Dept. Mines*, Ind. Min. Rept. No. 5.

Parks, W.A.
1912–17: Report on the building and ornamental stones of Canada; *Mines Branch*, Dept. of Mines, Nos. 100 (general and Ontario), 203 (Maritime Provinces), 279 (Quebec), 388 (Prairie Provinces), 452 (British Columbia).

SULPHUR

World demands for sulphur are large, and increasing, mainly because sulphuric acid is one of the main industrial materials, being particularly in demand for the manufacture of chemical fertilizers. Production has also increased and some authorities fear over-production. Large amounts of sulphur are produced in Canada from smelter fumes and the refining of petroleum. Certain mineral deposits and concentrator-tailings containing large amounts of pyrite and pyrrhotite are also being used in this country for the production of iron and sulphur. Such uses have improved the outlook for certain other deposits of these sulphides but prospectors should remember that these minerals are extremely common in many parts of Canada and are generally in concentrations that are small or lean. The important considerations in any attempt to recover sulphur values from pyrite are the location of the raw material with respect to markets for the end products and the nature and size of these markets.

In 1967 the encountering of elemental sulphur in two different areas of Alberta aroused considerable interest. In the Camrose area elemental sulphur was found in cores of drilled holes at depths of more than 3,000 feet. The amounts and grades, apparently, were not sufficient to encourage development. Elemental sulphur occurrences

were also found at surface and under shallow cover in northern Alberta. No economic deposits have been reported but exploration on some of these occurrences is continuing. Such occurrences offer possible opportunities for prospectors. If prospecting for deposits of this kind becomes very desirable, it may be worth remembering that dogs are reported to have been used in Finland to detect sulphide minerals in overburden, by scent, and that emanations of sulphur might be detected in this way.

In 1967 Canadian production of elemental sulphur was valued at more than $70 million, and that of sulphur in smelter fumes nearly $6 million. Increasing demands and prices, and the fact that sulphur is also imported into Canada, indicate favourable opportunities for the operation of suitable deposits.

Suggestions for Additional Reading

Bartley, C.M.
Sulphur; *Min. Proc. Div.*, Ann. Rev.

TALC AND RELATED MATERIALS

Ultramafic rocks containing the mineral talc and the impure talcose rock called soapstone are mined in the Eastern Townships of Quebec. Talc is also mined from dolomitic marble near Madoc, Ontario. Pyrophyllite, which resembles talc, is mined in Newfoundland. In 1966 the output of talc and soapstone was valued at $386,600, and that of pyrophyllite at $608,220. Imports in the same year amounted to more than $1 million, suggesting that well-situated deposits of good size and quality might be attractive.

Suggestions for Additional Reading

Stonehouse, D.H.
Talc and soapstone; pyrophyllite; *Min. Proc. Div.*, Ann. Rev.

TELLURIUM

Small amounts of tellurium are found as gold–telluride minerals, but deposits workable for tellurium alone are not likely to be found. Canadian production comprises recovery from copper and nickel refineries; the quantity in 1967 was about 82,000 pounds valued at $530,000.

Suggestions for Additional Reading

Killin, A.F.
Selenium and tellurium; *Min. Res. Br.*, Ann. Rev.

THORIUM

Canada is an important producer of thorium as a by-product of uranium ores. As the supply of these is large, prospecting for additional sources of thorium is not likely to be required in the near future.

Before 1957, only limited amounts of thorium were used, mainly in the manufacture of gas mantles. Supplies were obtained chiefly from beach placers in other countries. In that year demand increased sharply because of the development of thorium–magnesium alloys useful in the aircraft industry. The use of thorium nitrate in manufacturing gas-lamp mantles continues to account for a significant part of the demand. Thorium is radioactive, and an isotope can be converted in a reactor (by absorption of a neutron) to a fuel-isotope of uranium. This 'thorium–uranium fuel cycle' can be used successfully in advanced converter and breeder reactors. As these are now in early stages of development, authorities do not predict an increase in demand for thorium until at least 1985.

The uranium deposits of the Elliot Lake area contain about half as much thorium as uranium, and a plant designed to produce 150 to 200 tons of thorium compounds yearly was built there. The thorium is contained in the minerals monazite and brannerite, and as an impurity in uraninite. The occurrence of these and other thorium-bearing minerals is discussed in the references listed in connection with uranium.

TIN

Tin is widely used, mainly for making tin plate, solder, bronze and other alloys. Large amounts are imported into Canada, chiefly from Malaysia and Thailand. During World War II, when tin was in very short supply, considerable prospecting failed to disclose deposits that could be worked for this metal alone. A deposit found later in New Brunswick is being explored. The only tin produced in Canada at present is as a by-product of the treatment of ores of the Sullivan mine in British Columbia; a few hundred tons, as metal or concentrates, have been turned out annually in recent years.

The principal ore mineral of tin is cassiterite (tin oxide); stannite (sulphide of copper, iron, and tin) is less important, and other tin-bearing minerals are, in general, still less so. Tin occurs in quartz veins and associated granitic rocks altered to 'greisen', in pegmatites, in sulphide veins and massive deposits, and in placers derived from the foregoing kinds of deposits. Most of the world's production is from placers.

In the past, a little tin was saved in Canadian placer operations for gold, but more was discarded. More attention will probably be paid to such possibilities in future.

Most Canadian lode and placer occurrences are in a belt immediately west of the Rocky Mountain Trench and extending across much of the Yukon. Several others have been found in New Brunswick and Nova Scotia. These lie in three belts, one in central and one in southern New Brunswick, and one along central Nova Scotia (*see* Map 32-1964). The belt in southern New Brunswick includes the Mount Pleasant replacement deposits in shear and breccia zones in altered rhyolitic volcanic rocks which, although mapped as Mississippian age, may be older, and so the mineralization may be related to the Devonian granite of the region. As well as cassiterite and stannite, the deposit contains minerals bearing tungsten, molybdenum, and

other metals, and fluorite. The property, which was found by geochemical prospecting, is the scene of considerable exploration and treatment tests have been made. Several occurrences have been discovered in Slave and Superior Provinces; a few in the Bernic Lake area northwest of Winnipeg have been tested by drilling and shaft sinking.

The occurrence of tin in a wide variety of deposits indicates the desirability of testing all producing mines and advanced prospects for possible presence of tin. This could be done by spectrographic analysis of panning concentrates or samples.

Suggestions for Additional Reading

Jackson, W.H.
Tin; *Min. Res. Br.,* Ann. Rev.

McClelland, W.R.
1952: Tin in Canada: occurrences and uses; *Mines Branch,* Mem. Ser. No. 125.

Mulligan, R.
1966: Geology of Canadian tin occurrences (Report and Map 32-1964); *Geol. Surv. Can.,* Paper 64-54.

Pentland, A.G.
1943: Occurrence of tin in the Sullivan mine; *Trans. Can. Inst. Mining Met.,* vol. 46, pp. 17–22.

Riddell, J.E.
1962: Tin in southern New Brunswick, with special reference to the Mount Pleasant deposit; *Can. Mining J.,* vol. 83, no. 4, pp. 69–75.

Warren, H.V., and Thompson, R.M.
1944: Tin in western Canada; Western Miner, Aug., pp. 40–46.

TITANIUM

One of the largest titanium-bearing deposits in the world is being worked north of Havre St. Pierre, Quebec, to produce concentrated titanium dioxide which is being used increasingly in the pigment industry. In 1966 the Canadian production of titanium oxide was valued at $21.6 million. Although titanium metal is being used for certain special applications, both as a pure metal and as an alloy, the total amount consumed is relatively small. A new discovery would probably have to be large in size, have a high titanium dioxide content, be conveniently located for cheap transportation, and be amenable to concentration, in order to compete with large deposits already known in Canada and elsewhere. Because most deposits are magnetic, prospecting would probably be aided by use of dip needles or ground or air magnetometers.

The principal ore minerals of titanium are titaniferous magnetite and ilmenite (both oxides of iron and titanium), and rutile (oxide of titanium). In the industry, ores are classed as titaniferous magnetite ore if they contain less than about 20 per cent titanium, and as ilmenite ore if they contain more than that.

Occurrences of ilmenite and titaniferous magnetite are fairly common in Grenville Province of the Canadian Shield. Most are magmatic segregations in gabbro and anorthosite, a rock composed almost entirely of plagioclase feldspar which commonly carries ilmenite and magnetite in small amounts as accessory minerals. Some of these deposits, notably one near St. Urbain, Quebec, have been worked for many years on a relatively small scale.

The presence of ilmenite in the Havre St. Pierre or Allard Lake region was first reported by the late J.A. Retty, then of the Quebec Department of Mines, as a result of a geological reconnaissance in 1941. This led to the staking of claims that were acquired by two large American mining companies which, from 1944 on, carried on much prospecting, geological exploration, aeromagnetic surveys, and diamond drilling, that resulted in the discovery of eight separate ilmenite deposits. By 1947 large tonnages of ore were indicated, particularly in one deposit, and the following year construction of a railway from Havre St. Pierre to the deposit was begun. A plant for treating the ore was built at Sorel, Quebec. The Allard Lake deposits are in the northeast corner of a large intrusive body of anorthosite. They are black dykes, lenses, and sill-like bodies containing masses and disseminations of ilmenite. They are believed to be related in origin to the anorthosite, but to have been introduced, after it was solidified and fractured, as a late stage of the general intrusive process. The ore is reported to average 35 per cent titanium oxide and 40 per cent iron.

Suggestions for Additional Reading

Gross, G.A.
1965: Geology of iron deposits in Canada; *Geol. Surv. Can.,* Econ. Geol. Ser. No. 22.

Hammond, P.
1949: Geology of Allard Lake ilmenite deposits; *Trans. Can. Inst. Mining Met.,* vol. 52, pp. 64–68.
An article on the geology and method of exploration of these deposits and their nature and origin.
1952: Allard Lake ilmenite deposits; *Econ. Geol.,* vol. 47, no. 6, pp. 634–649.
A paper on the geology and ore deposits in Allard Lake region, with a discussion of exploration methods.

Retty, J.A.
1944: Lower Romaine River area; *Que. Dept. Mines,* Geol. Rept. 19, pp. 3–29.
The report of a geological survey that called attention to titanium occurrences.

Rose, E.R.
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TUNGSTEN

Tungsten (also called wolfram) is important for making certain kinds of steel and for tungsten carbide tools. It is obtained from the minerals scheelite (calcium tungstate) and wolframite (tungstate of iron and manganese). Scheelite occurs usually in quartz veins formed at high to moderate temperatures, silicified zones in granite, and contact

metasomatic deposits. It has been found in many places in the Canadian Shield and the Cordilleran and Appalachian regions, and a few occurrences of wolframite have also been found. Tungsten minerals including ferberite also occur in relatively small amounts in Canadian placers.

Canadian production in the last few years was entirely from the mine of Canada Tungsten Mining Corporation in the Cordilleran region in the southwestern part of the Northwest Territories. This deposit was brought into production in 1962 with the erection of a 300 ton-per-day mill. With an average grade of about 2.5 per cent WO_3 it is one of the highest-grade deposits in the world. Copper was found at the site in 1954 and scheelite was discovered a few years later by panning and lamping. The deposit is a skarn zone in Paleozoic limestone near a granitic (quartz monzonite) stock.

Scheelite was formerly mined near Salmo, B.C., from lenticular contact metasomatic deposits in limestone and skarn near granite, and at Hazelton, B.C., from a quartz vein in a diorite stock. These mines were closed when contracts expired.

About 4 million pounds of tungsten was produced in Canada in 1966, mainly for long-term export contracts. Demand for additional deposits is not strong at present. The usefulness of fluorescence in prospecting for scheelite deposits and exploring them has been amply proven.

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URANIUM

Canada is a leading producer of uranium, a metal now mainly in demand as fuel for the generation of nuclear power. She also has the largest known reserves of uranium ore. Uranium was the chief metal produced in Canada in 1958 and 1959, after which markets for it declined because of temporary over-supply. Production is again increasing and the long-term outlook is favourable. Output in 1967 was about 7½ million pounds of uranium oxide (U_3O_8) valued at nearly $50 million.

The radioactivity of uranium (*see* Chapter 12) permits use of special aids such as Geiger counters in prospecting for the metal, but their effective use is not as simple as is commonly supposed. The radioactivity of uranium causes certain governmental controls on prospecting and mining and certain precautions when dealing with high concentrations (there are no special hazards regarding concentrations encountered in prospecting or when testing the surface of deposits). The great emphasis on searching and mining for uranium in Canada from 1948 to 1960 resulted in much experience in prospecting for it, in the appraisal of discoveries, and in mining uranium. It also was responsible for the collection and processing of much information on the geology and mineralogy of deposits. Much of this experience and information was summarized as fully as could be done in a single medium-size volume in "Canadian Deposits of Uranium and Thorium" (Econ. Geol. Ser. No. 16, 2nd ed.) a publication that contains a fairly complete bibliography up to 1960. Since then relatively few new prospects have been found, and comparatively little additional information on techniques for conventional prospecting for uranium deposits has developed, although some significant improvements have taken place in advanced techniques, as mentioned later.

The following notes are intended to serve two purposes: (1) to outline the fundamentals of the subject for persons unfamiliar with it and who do not desire the fuller treatment in "Canadian Deposits of Uranium and Thorium" or who will use the notes as an introduction to it, and (2) to summarize the main information that developed after 1960, and to provide the main references to it. The references do not include some recent papers on special prospecting techniques that are listed in other chapters. The notes are a little longer than those for other main metals, to explain certain unusual features of prospecting for radioactive deposits and regulations respecting prospecting and mining for them.

History

Canadian activities related to radioactive minerals occurred in six stages, an understanding of which is helpful in appreciating the present situation and the future probabilities. The first stage, which may be called the academic one, lasted from the first discovery of a uranium mineral in this country, more than a century ago, until the discovery of a rich radioactive deposit at Great Bear Lake in 1930. This led quickly to the second, radium, stage during which the deposit was mined for radium until 1940. This period was followed by a secret stage when the mine was worked for uranium as a project connected with World War II, and when unpublicized efforts were made by agencies of the Canadian government to find and develop additional

supplies of uranium. By late 1947 the probable future demand for large amounts of uranium for peaceful purposes was sufficiently evident, and the needs for maximum security were sufficiently reduced, to cause the Canadian government to permit staking and mining for uranium by the public, under certain restrictions. This began what may be called the 'public-participation stages' of which there have been three: a period from 1948 to about 1960, characterized by intensive prospecting, much mining, and increased research on the geology of deposits; a slack period caused by temporary over-supply, lasting until about 1967; and the present one during which future markets seem more promising and in which some mines are being re-opened and advanced prospecting and testing of prospects are being undertaken. Each of these stages is described a little more fully in the following paragraphs.

The element uranium was isolated and described in Germany late in the 18th century and the phenomenon of radioactivity, discovered in France about 100 years later, resulted in 1898 in the discovery of radium as a component of uranium minerals. Supplies of radium were first obtained mainly from Czechoslovakia (Bohemia). About 1912 radium was also obtained from vanadium ores in the United States. A mine in the Belgian Congo became the chief source in the early 1920's, resulting in a fairly complete monopoly. After the first published description of a uranium mineral in Canada in 1847, mineralogists and geologists here gradually took increasing interest in radioactive minerals, and several occurrences were discovered and described. Although it became known that uranium was fairly abundant in the rocks of the earth's crust as a whole, less so than copper, lead, or zinc but more abundant than gold or silver, the relatively few occurrences in which uranium minerals had been found caused the metal to be considered among the rarer elements. This confusion was probably accentuated by the association of uranium with radium, which is indeed rare. In 1914 the Geological Survey of Canada issued a small handbook on prospecting for radium, and after 1920 H.V. Ellsworth of its staff specialized in 'rare-element' minerals, including uranium, making valuable contributions to their mineralogy and to early applications of radioactivity to dating the ages of minerals. Geiger counters, which were used in complicated laboratory assemblies after the principle was discovered in Germany in 1928, were used experimentally for field investigations in Canada soon afterwards. The first such equipment, weighing 55 pounds, was assembled and tested by professors at the University of British Columbia in 1932. Ellsworth and two assistants made and used a set weighing 21 pounds in 1934.

The period of mining for radium in this country resulted from discovery of veins in 1930 at the east shore of Great Bear Lake, almost on the Arctic Circle, as a result of a prospecting trip soon after bush flying began to make searching in remote places more practical. This site was chosen by G.A. LaBine of Eldorado Gold Mines because he had read the account of an early geological reconnaissance of the lake which stated that cobalt and copper had been observed there; he knew that silver is commonly found with cobalt and thought the area might have possibilities for silver, a metal in which he was particularly interested because he had worked at Cobalt, and which might be valuable enough to be mineable in such a remote region. He found silver and also pitchblende, the principal mineral for radium. He told the writer recently that he recognized the pitchblende because he had been shown a specimen during a course in prospecting. Much pioneering was required to overcome the problems of transportation and to establish a mine, but production began in 1932. A refinery built at Port Hope, Ontario, by the company began turning out radium bromide in 1933, in quantities that soon reduced the world price for radium. The mine was closed in 1940 because the company had more than enough refined radium to satisfy the immediate demand, and because of difficulties of operating in wartime.

Two years later, research on the possibilities of 'splitting' uranium atoms caused the Canadian government to ask the Eldorado company to reopen the mine and the refinery secretly, for the production of uranium. Minerals that contain radium also contain three million times as much uranium, but up to that time virtually no market existed for uranium although a little was used as a pigment and for making certain chemical reagents. Most of the uranium in ores or concentrates worked for radium was discarded or stockpiled in dumps. The mine, which had been allowed to fill with water, was pumped out and the refinery resumed operations in 1943, at which time the name of the company was changed to Eldorado Mining and Refining Limited*. The refinery was not equipped for making elemental uranium, but made a high-grade uranium concentrate that was sold and shipped to the United States where it was used, along with supplies from the Congo, for the joint American–English–Canadian atomic research project. In 1944 the other governments concerned asked the Canadian government to take over the Eldorado Company; this was done by buying the shares and establishing a crown corporation. As a security measure, staking and mining for radioactive minerals were prohibited in 1943 by regulations of the federal government for the Yukon and Northwest Territories, and by provincial regulations in provinces likely to be concerned. The Eldorado Company and the Geological Survey were charged with prospecting for additional sources of uranium and with related research.

One of the first steps was to develop Geiger counters that were more practical for field use. The National Research Council and the Geological Survey jointly developed two models that were efficient for their time, and tested them on the surface of the Eldorado claims. A supply of these counters was then made by the Research Council for the Eldorado and Geological Survey parties and for donating to other Commonwealth countries. These were the forerunners of commercial models manufactured in Canada later when security restrictions were removed. Another early step was the re-examination of the substantial number of localities at which radioactive minerals had

* Now Eldorado Nuclear Limited.

been reported over the years in Canadian geological literature. One of these was the Goldfields area at Lake Athabasca where F.J. Alcock of the Geological Survey had reported an occurrence of pitchblende at a copper prospect. Prospectors there had pointed out the mineral to him when he was examining the prospect during his geological mapping of the area, and told him that they recognized it because they had seen specimens from the mine at Great Bear Lake. The presence of pitchblende was confirmed by Ellsworth when he examined specimens obtained by Alcock from the Nicholson property. Two geologists on behalf of Eldorado and the Geological Survey who examined the Nicholson showings in 1944 as part of the routine coverage, and who were more impressed with the possibilities of this area than any others they had visited except the Great Bear Lake area, advised Eldorado to concentrate its prospecting activities there. The company engaged prospectors, mining engineers, and geologists experienced in work for gold and other metals and taught these men the additional knowledge then available regarding pitchblende and the use of counters. The Geological Survey began more detailed study and mapping of the Goldfields region and attached prospectors to its parties. This was an unusual procedure except in wartime when strategic minerals were concerned. These activities soon revealed about one thousand occurrences at which pitchblende was identified or where strong radioactive anomalies were found. One of these became Eldorado's Ace mine, at which production was begun in 1953. Although some of the other occurrences had more impressive surface showings, the Ace was selected for detailed testing because it was associated with a prominent fault that seemed to offer better structural possibilities. Eldorado's Fay and Verna mines were developed later along the same structure.

Late in 1947 the probability of demands for still larger amounts of uranium for peaceful purposes and the lessening of requirements for security caused the Canadian Government to lift the ban on private staking and mining although some controls were necessary, and to publish as much as possible on prospecting techniques and the geology of known uranium occurrences. The provincial governments also removed their restrictions. Coming at a time when prospecting for gold and other metals was not particularly encouraging, these remissions began a period of great emphasis on uranium by mining companies, experienced full-time and spare-time prospectors, and the general public. The reporting of discoveries and the issuing of permits for advance prospecting and mining by the Atomic Energy Control Board were required as was the submission of reports on work done under these permits. The latter reports were at first required monthly but this was later reduced to annually. A minimum of 0.05% uranium or thorium oxide or their equivalent in terms of radioactivity was set as the limit for an occurrence to be classed as radioactive for the purpose of the regulations. The inclusion of a few statistics here will not only provide an idea of the events of this period but will also indicate the great difference between a uranium occurrence and a uranium orebody. From 1948 to 1960 an estimated 12,000 radioactive occurrences above the 0.05% limit were found in various parts of Canada. Testing permits for more than 100 man-days of work were issued for 432 properties, 359 of which were tested by diamond drilling. Underground workings were driven to test 117 properties, most of which had been diamond drilled earlier. Nineteen producing mines equipped with their own treatment plants resulted, along with seven others from which ore was shipped to nearby plants because the deposits were too small to warrant separate plants. The first large privately owned mine to begin production was the Gunnar, opened at Lake Athabasca in 1953. The greatest developments, however, were in the Elliot Lake area of Ontario where the Pronto mine was brought to production in 1955, after a conventional prospector had found radioactivity in old pits on a copper or gold prospect. By applying information obtained from the mode of occurrence of the Pronto deposit to a map made by W.H. Collins of the Geological Survey of Canada several years earlier, F.R. Joubin and geologists associated with him directed prospecting parties to a continuation of the general Pronto structure through the Elliot Lake area. Their efforts, combined with those of company and government geologists who restudied the area during the next few years, resulted in the establishment of eleven additional mines. By the end of 1966 these and the Pronto had produced uranium valued at about $1,398,000,000. Most known reserves of ore are at Elliot Lake. In the Bancroft area of Ontario two mines with individual treatment plants and two shipping mines began production in 1956 and soon afterwards. A plant to produce fuel elements for nuclear reactors began operation at Port Hope in 1958.

Sales of uranium from Canadian mines were made through the Eldorado company, mainly to the United States Atomic Energy Commission on contracts calling for completion in 1963 but with options for extension. Late in 1959 the Commission indicated that it would not take up such options, but arrangements were made to 'stretch out' the termination of some of the Canadian contracts and to permit companies to negotiate private arrangements among themselves so that the contracts could be filled by the companies best able to do so. Arrangements were also made to permit private companies to seek other foreign markets, subject to controls and export permits, and some uranium was bought for stockpiling. In spite of these efforts to ease the period of over-supply most mines closed either because of termination of contracts or exhaustion of ore. By 1966 the only mines in operation were three at Elliot Lake and the Eldorado at Beaverlodge.

Predictions of increases in demand caused more activity in 1967. Reopening of some mines was begun and Eldorado was preparing another deposit for production at its property at Beaverlodge. Ore from this deposit, which was found and drilled several years ago, will probably be trucked to the existing plant. Additional drilling was done on a deposit found a few years ago at Agnew Lake, 50 miles east of Elliot Lake. Claims that had lapsed at Beaverlodge were re-staked and further testing of some prospects was done. Radioactive discoveries in granitic rocks and pegmatites north of Anticosti Island attracted attention.

Minerals

Although about fifty different uranium minerals have been identified from Canadian occurrences most of these species occur only in small quantities that are not of interest to prospectors. Six species or varieties of ore minerals have been mined in Canada, and only a few others in other countries. The Canadian ore minerals are *uraninite* (uranium oxide) and the variety of uraninite called *pitchblende*; *brannerite* (*see* below); *monazite* (*see* below); *uranothorite* (silicate of thorium and uranium); and *uranophane* (hydrated silicate of calcium and uranium). Brannerite is a complex uranium–titanium mineral, but it has been suggested that some of the material occurring in the ores at Elliot Lake may be a mixture of two simpler uranium and titanium minerals; the minute particles of the material in question have delayed full settlement of this question. Monazite is essentially a phosphate of cerium-group metals (*see* section on rare earths). Some Canadian examples of monazite are unusually high in uranium, possibly because uranothorite is intimately mixed with them.

Supergene uranium minerals are common at or close to the surface of Canadian deposits of the metal but only in the case of one deposit, the Gunnar, has it been found in sufficient quantities to be a main factor in the ore; this is because of unusual circumstances explained below. Most supergene uranium minerals are of characteristic yellow or orange colour and are, therefore, valuable clues in prospecting but this is almost always because they call attention to the presence of uraninite or pitchblende rather than because they themselves occur in quantity. As the different supergene minerals are difficult to identify precisely except by laboratory methods it is usually sufficient for prospectors, and for geologists or engineers engaged in early-stage investigation of deposits, to refer to the supergene minerals collectively as uranium stain. Precise identifications become desirable during advanced studies of deposits and when possible methods of treating ores are being investigated.

The most important minerals for a person prospecting for uranium, or investigating radioactive discoveries, to be able to recognize are uraninite, pitchblende, and 'uranium stain'. A radioactive mineral of black or brownish black colour, occurring in cubic crystals, is probably uraninite. Pitchblende has about the same composition as typical uraninite but does not occur in visible crystals, except rarely when viewed under a microscope. It is strongly radioactive and is normally black, but many occurrences are reddish brown because of associated hematite, and others are dark grey because of associated silica. Many occurrences have a pitchy or waxy appearance and many have partly rounded (botryoidal) shapes. Uranothorite is difficult even for experts to identify in the field, but if a black, waxy, strongly radioactive mineral is found in irregular masses in a deposit of the general pegmatitic class it may be suspected of being uranophane.

Deposits

Uranium has been found in Canada in a wide variety of geological classes of deposits, but present and past producing deposits in this country are limited to only three general classes. The most productive class and the one responsible for most reserves of ore is conglomerate of Proterozoic age. The next most productive class comprises various kinds of veins and disseminations containing pitchblende, mined in the Beaverlodge area of Saskatchewan and in Northwest Territories. The other productive class consists of a complex type of pegmatitic and related deposits unlike typical pegmatite, which were mined near Bancroft, Ontario. The only other classes of deposits known to have been mined extensively in other countries, but not here, are deposits of uraninite and other minerals in sandstone, shale, and limestone in western United States; some of these deposits contain vanadium as well as uranium, and certain others are associated with beds of lignite.

All productive uranium deposits in Canada have been in the Canadian Shield, which also contains by far the greater part of known occurrences. A substantial number of occurrences have, however, been found in the Cordilleran and Appalachian regions and some low-grade ones have been found recently in the southern part of the Interior Plains. Most of the known occurrences or areas containing several occurrences are shown on a map of Canada accompanying "Canadian Deposits of Uranium and Thorium". The productive deposits and many of the known occurrences are fairly close to the boundary of the Shield. The locations of some of these are attributable to certain geological conditions that happen to occur in those places but are not necessarily confined to them. However, the reason for the marginal distribution seems also to be partly due to accessibility for prospecting owing to the presence of large lakes and rivers at or close to the boundary of the Shield, and also partly to the natural tendency for persons to concentrate prospecting in areas where the metal sought has already been found. It is therefore quite possible that additional mines or discoveries may be found in other parts of the Shield or in other of the main geological regions.

Pitchblende occurs in many ways in deposits of the general vein and disseminated forms, several forms commonly being present within one orebody. These forms may be fairly regular veins, irregular masses, stringer systems (commonly with disseminations of pitchblende in the rock between stringers), and breccia fillings. In some places pitchblende is massive, in others it is in streaks or grains visible without magnification, and in many others the grains are of microscopic size. Known Canadian pitchblende deposits are of two general mineralogical types called simple and complex, but these grade into one another in some mines. In the simple type the only other main metalliferous mineral is hematite, and gangue generally consists of silicified rock, quartz, chlorite, or calcite or combinations of these. In the complex type pitchblende may be associated with a variety of minerals such as native silver, silver, copper, cobalt, nickel, and other sulphide and sulpharsenide minerals, in gangues similar to those mentioned above. A characteristic brick-red alteration of the rocks near deposits of both types, caused by introduction of hematite, is a useful guide in prospecting and in the testing of deposits. Most deposits at Beaverlodge are of the simple type, and those at Great Bear

Lake were of the complex type. The former Gunnar deposit at Beaverlodge was of another mineralogical type, being a mixture of pitchblende and the supergene mineral uranophane disseminated in a pipe-like body of much fractured albite–calcite–chlorite rock lying close to the intersection of two faults. The grade of ore was fairly consistently 3.4 pounds of U_3O_8 a ton. Unlike most Canadian deposits the supergene mineral continued in about the same ratio to pitchblende from the surface to the lowest level, at a depth of about 1,200 feet. This is believed to have been owing to the porous nature of the host rock and because the deposit was at the shore of Lake Athabasca and mainly below the level of the lake. Water under pressure issued from some of the holes drilled to test the deposit, therefore it is believed that lake water circulated through the deposit causing supergene mineralization at depth.

Production from conglomerate ores has been confined to the Elliot Lake (Blind River) area in Southern Province, north of Lake Huron. Radioactive conglomerate occurs in beds near the base of the Huronian strata that rest uncomformably on Archean rocks. The conglomerate consists of tightly-packed quartz pebbles, the matrix containing pyrite, 'brannerite', uraninite, monazite, and other minerals. Only certain beds of sufficient extent and thickness, and containing more than about 0.06 per cent U_3O_8 and averaging about 0.12 per cent, are considered ore. Most students of the subject now believe that the uranium minerals were derived from rocks or mineral deposits that existed in Archean rocks northwest of Elliot Lake, and were eroded and transported along with the pebbles and deposited mainly in channels that now represent the belts of conglomerate of sufficient thickness and grade to be ore. Such gravels could readily become conglomerate by normal rock-forming processes but some of the characteristics of the deposits at Elliot Lake are difficult to explain by simple consolidation. It is believed, therefore, that metamorphism probably caused recrystallization of at least some of the original components of the 'brannerite', that some uranium may have been introduced or mobilized, and crystallized, by some process other than the action of streams. Most placer deposits contain more magnetite than do the conglomerates of Elliot Lake; therefore it has been suggested that sulphur may have been introduced, thus causing conversion of magnetite to pyrite.

The productive deposits at Bancroft are or were irregular bodies having some of the characteristics of lenticular dykes, composed of granite and syenite together with pegmatitic and metasomatic phases. These 'dykes' cut the wallrocks in places and replace them in others. The ore minerals were uranothorite and uraninite. The mineable deposits were clusters of 'dykes' spaced sufficiently closely to permit mining from a single shaft or adit, and averaged about 0.1 per cent U_3O_8. The deposits were in the border zones of three masses of granite, syenite, and related rocks, each about 6 miles in diameter. Because of the complex nature of the deposits it is impossible to assign them to any one simple classification. The shape and structure of the deposits are more typical of pegmatites but much of the material in them is too fine grained to be called pegmatite and is properly considered granite or syenite. The deposits are, however, not comparable to certain low-grade radioactive deposits that consist of entire stocks or of large parts of stocks, containing radioactive minerals as accessories, nor are they comparable to typical pegmatites.

The intensive prospecting and research on uranium deposits in this country showed that uranium occurs in many other types of deposits that have not yet been proved to be mineable. Only a few can be mentioned briefly here, but other publications contain information on them. An agreement for sale was obtained for uranium from the Rexpar deposit in central British Columbia but the property did not reach the producing stage before the decline in emphasis on uranium. Two deposits were found in metamorphosed sedimentary rocks intruded by granodiorite. The radioactive mineral in one zone was uraninite and, in the other, uranothorite. Uranium contents were reported to average 1.53 to 1.75 pounds of U_3O_8 per ton.

A recent discovery in the Johan Beetz area north of Anticosti Island that has attracted a good deal of attention is described as a stock of complex pegmatitic granite in which uranium minerals are associated with magnetite. Many claims have been staked on this stock, and in the vicinity where radioactive pegmatite dykes are reported to have been found.

Although uranium deposits have been mined extensively in sedimentary rocks underlying much of central United States, preliminary investigations of similar strata in the Interior Plains of Canada did not reveal significant deposits. These investigations included examination of many deposits of coal and lignite because some uranium deposits in the United States are associated with them. Canadian occurrences were tested for radioactivity or sampled by the Geological Survey of Canada but the highest content of three hundred and fifty-five samples was 0.008 per cent U_3O_8. A sample of ash from a coal seam in the Eastend area of Saskatchewan sent to the Geological Survey by the Saskatchewan Department of Mineral Resources, however, showed 0.057 per cent U_3O_8 equivalent. During the last few years companies have investigated lignite deposits in the Cypress Hills and Wood Mountain areas of Saskatchewan and have found supergene uranium minerals in sedimentary rocks not far above lignite deposits. Uranium contents between 0.05 and 0.1 per cent U_3O_8 are reported to have been obtained in places.

Outlook

Demands for uranium showed signs of increasing in 1966 and several authorities have stated that this trend will probably continue for some time. For example, in his annual report for 1967 the President of Eldorado Mining and Refining Limited predicted that 'proven and developed' reserves of uranium ore in the western world would not meet the demand beyond 1973, and that further developments of known ore deposits or newly discovered deposits or the utilization of deposits of lower grade will be necessary. Prices for uranium are not quoted regularly because no open market exists for it. The prices at which contracts were made were not usually revealed, but one published

statement indicated that the average price of the earlier contracts was $10.00 a pound of contained U_3O_8. Prices are understood to have been lower during lessened demands the last few years. The only Canadian price published in 1967 stated that three contracts made by Rio Algom Mines Limited for deliveries in 1969–83 averaged $7.14. The President of Eldorado expressed doubt that substantial additional deposits that could be worked at price ranges of about $10.00 per pound would be found, and that the users of uranium for nuclear power plants might therefore have to pay higher prices.

The writer considers that the possibilities of finding new uranium discoveries or of making additional tests on known prospects in Canada can be summarized as follows. Demands for the next few years can be met by ore, blocked out by underground workings or indicated by diamond drilling, at mines now producing or at certain mines that were closed because of decline in demand. Geological conditions at some of these deposits are favourable for the revealing of additional ore at current prices for uranium by further detailed geological studies and drilling. Also, some of the producing or formerly producing properties have possibilities for the discovery of additional, separate deposits that might be found by suitable combinations of advanced prospecting techniques.

Some properties contain considerable potential ore represented by uranium-bearing material that is below present ore grades or in quantities that, although of present ore grade, were considered to be too small or otherwise unsuitable for mining. Some of this material is at producing or formerly producing properties, and some is represented by partly tested prospects. In the event of an increased price for uranium such material, particularly that at already developed properties, would become economically attractive. Information on some of the deposits of this kind is contained in various government reports and annual reports of companies. The files of many mining companies doubt less contain other information.

Recent publications of the Beaverlodge area, for example, contain additional generalizations on the structural controls of ore deposits, which might be applied to further prospecting or testing. In this connection it may be noted that the Gunnar deposit was at the north shore of Lake Athabasca and that the lake bottom within a few miles seems an obvious place for detailed geological and geophysical investigations coupled with information obtained from the nearby shore and islands.

Because the producing uranium areas are already largely or entirely staked, some companies have begun to test the further possibilities of some of the better prospects already found in other areas, or to search for additional deposits in such areas. For such cases it may be worth noting that past experience in mining for metals in general has shown that although experience and knowledge of conditions in one mining camp are useful in appraising the possibilities of other districts, dangerous oversimplifications can be made by carrying such comparisons too far.

Many parts of Canada are favourable in a general way for the discovery of additional deposits. These include areas in which prospects have already been found and areas where the geology is favourable in a general way but in which no occurrences have yet been found. Roscoe (1966) has recently summarized such possibilities. His summary includes localities east and west of Elliot Lake where the geology, although not identical with that of the Elliot Lake geological basin, contains somewhat similar conditions. He also indicates in a general way areas in many parts of the country where the geology is theoretically favourable for uranium deposits of some kind.

The best opportunities for future prospecting for uranium are believed to be for advanced prospecting projects suited to the area to be covered. Although some of the productive deposits were found by conventional prospecting, outcrops in most parts of southern Canada and in the principal uranium regions farther north have been fairly thoroughly prospected by conventional methods. Also, there are bound to be outcrops in remote places that have not yet been prospected adequately. These would provide opportunities for independent conventional prospectors who can arrange for sufficient backing to permit work in such places and also for amateur spare-time prospectors who may be posted to such areas or travelling through them. Such persons should be qualified by having attended a prospecting course or having studied a book such as this.

Excepting remote chances there seems to be no reason for resumption of the kind of unqualified prospecting for uranium that was so widespread during the uranium boom. This statement does not apply to qualified spare-time prospectors who devote an amount of time and effort to study and practising comparable to that spent by any enthusiast taking up a hobby or sport. One of the mines at Bancroft and several prospects that merited substantial testing were found by well qualified spare-time prospectors who deserve the greatest admiration. No significant finds were made by the hundreds of vacationists and others who seem to have been so deluded by publicity and advertisements that no amount of literature, correspondence, and lectures could convince them that there was more to prospecting for uranium than finding a place where moderate readings could be obtained with a Geiger counter. Persons who undertake to prospect for uranium would be well advised to study the information contained in Chapter 12 on radioactivity detectors for use on the ground. They should also understand and abide by the few regulations now applying, which are discussed in Chapter 17 and summarized briefly below. Failure to comply might result in difficulties in obtaining mining or export permits later.

Regulations require that the Director of the Geological Survey of Canada be notified precisely of any localities where strong radioactivity is obtained from samples or where assays showing 0.05% or more uranium or thorium are obtained. This does not imply that the Survey will be able to examine the occurrence. It is required because the reporting of discoveries is considered necessary for general security reasons, and because the availability of such information made it possible to provide more comprehensive information on favourable conditions for prospecting for

uranium than was possible for other metals for which reporting is not required.

After significant assays have been obtained, and the Geological Survey has been notified, it is unlikely that independent prospectors would be able to do more than try to interest a mining company in the discovery. During the uranium boom the Geological Survey advised many persons who found or thought they had found uranium, but it is believed that this should now seldom be necessary except in the case of companies, because of the amount of information available in publications and in courses on prospecting.

Suggestions for Additional Reading

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VANADIUM

Vanadium has important uses, mainly as an alloying ingredient in high-speed tool steels and other alloy steels. It has not been produced in Canada until recently and few occurrences are known here. The chief minerals from which it is produced in other countries are patronite (a complex mineral containing large amounts of vanadium sulphide), roscoelite (a vanadium-bearing mica), carnotite (hydrous vanadate of uranium and potassium), and vanadanite (lead vanadate). Vanadium is obtained chiefly from carnotite-bearing sandstones of Mesozoic age in the Colorado Plateau region of the United States. Production in Canada commenced in 1964 with the recovery by Canadian Petrofina Limited of vanadium oxide from Venezuelan crude oil.

During the last few years vanadium has been found in relatively small quantities in several hydrothermal uranium deposits in Beaverlodge region, Saskatchewan, where it occurs in a new iron vanadate mineral named 'nolanite'. A small exposure of a thin bed of hard, black, vanadium-

bearing rock lying between two lava flows of the Valdes group, probably of Triassic ore, is reported on the north end of Quadra Island, northeast of Vancouver Island. Titaniferous magnetite and ilmenite ores, particularly those in anorthosite, contain some vanadium that might be recovered from slag if sufficiently abundant. The possibility of discovering carnotite-bearing strata in the Interior Plains cannot be ruled out, but because of the prominent yellow colour of the mineral it is reasonable to suppose that any occurrences would have been detected in the millions of drill-cuttings examined by oil geologists.

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ZINC

In contrast to lead, the use of zinc is comparatively recent. It is used mainly for galvanizing iron and steel to prevent rusting. Such use in connection with the underparts of automobiles is increasing. Zinc is also much used for die-castings in brass and other alloys. Canada is the largest zinc-producing country of the world. In 1967 this metal was our fifth largest mineral commodity, accounting for 7.2 per cent of the total mineral production. The value of Canadian production in 1967 was more than $314 million. This was derived mainly from Ontario, Quebec, Northwest Territories, New Brunswick, and British Columbia, in that order.

History

Most Canadian zinc is derived from deposits containing various amounts of copper, lead, or silver as well as zinc. In some of these zinc is the principal metal, and in others it is subordinate. The history of zinc mining in Canada is closely related to that of the other metals mentioned above and is partly explained in the notes on them.

Canada's important place in world zinc production began soon after 1920 with the opening of the Sullivan mine in southern British Columbia, and was related to the development of the flotation method of concentrating ores, the expansion of the smelting and refining plants at Trail, B.C., to include a custom concentrator, and the operation of the smelter there partly on a custom basis. This allowed production from many lead–zinc–silver mines in the province, and elsewhere, which were not owned by Cominco.

Output of zinc was greatly expanded with the opening of large copper–zinc and zinc–copper mines in the Canadian Shield. This began in 1927 in the Noranda area of Quebec, where production has recently been increased by operation of the Lake Dufault and other mines. Large production began near the Saskatchewan–Manitoba boundary in 1930 and 1931 with the opening of the Hudson Bay and Sherritt-Gordon mines. Production was again increased substantially by the beginning of the Manitou operation near Val d'Or, Que., during World War II, and the mines at Manitouwadge, Ont., about 1957. Large production from mines in the Matagami area, Que., began in 1963. The Appalachian region became an important producer in 1928 with the opening of the Buchans mine in Newfoundland, and initial production at Bathurst, N.B., about 1957.

The beginning of zinc–lead production at Pine Point south of Great Slave Lake in 1965 caused a large increase in Canadian output and a change in the regional pattern of production. The developments at Pine Point are reviewed here at some length because they provide significant examples of prospecting history, of changes in techniques, and of deposits in an environment not previously productive in this country.

During the Klondike rush some of the stampeders attempted to reach the Yukon from Edmonton via the Mackenzie waterway, and thence westward across the mountains. One of the parties learned from local Indians of a mineral occurrence near Pine Point and persuaded them to act as guides to it. Claims were staked in 1898 but interest soon lapsed because samples taken by an officer of the Geological Survey of Canada, who visited the occurrence in the following year, failed to show precious metals when assayed; the region was then too remote to make deposits of base metals attractive.

Testing by means of surface pitting and preliminary drilling was begun in 1921 by a syndicate, and continued by a company in which the forerunner of the present Cominco Ltd. and Ventures Limited participated. Work was discontinued during the depression and resumed under a concession agreement. In 1936 an officer of the Geological Survey had pointed out that the deposits were approximately on the projection of major faults mapped in the Shield some 30 miles to the east (*see* Pl. 17); aeromagnetic maps published later by the Survey helped in the tracing of these faults. The area is almost entirely covered by overburden which required long and costly probing by diamond drilling. The work was serviced from an air strip. The gradual exploration of the property was based on theoretical geological concepts mainly by company geologists. Conventional prospectors played a part in the original staking, and geophysical surveys were a contributing factor. Many isolated deposits were indicated at first and it was hoped that these might in the aggregate permit a commercial operation, but larger bodies found later are the basis of the present mining. A railroad, town, and hydro-electric installations were built and a large open-pit mine was begun. Ore was shipped to British Columbia for tests in 1964 and high-grade ore shipments were made in 1965. A concentrator with a capacity of 5,000 tons a day was completed late in 1965.

The successful development at Pine Point resulted in much staking in the neighbourhood and exploration mainly by geophysical methods, which has already led to a discovery on the Pyramid property that has been acquired by Pine Point Mines Limited, a Cominco subsidiary.

Another great addition to Canadian zinc resources resulted from the discovery and development of the Kidd Creek deposit about 20 miles north of Timmins, Ontario. Smaller base-metal deposits were known in this district and the geology was favourable in a general way, but the area is covered extensively by overburden which prevented adequate conventional prospecting and geological studies. The discovery is attributed to geophysical surveys made about 1964, but details of the manner of discovery and geology of the deposit are not yet available. After the deposit was tested a large open-pit operation was prepared and the first of three 3,000 ton-per-day concentrating units began to operate late in 1966; the other units were in operation early in 1967, which made this one of Canada's largest mines.

Minerals

Sphalerite (zinc sulphide) is by far the most common primary zinc mineral. It oxidizes readily to form such secondary minerals as smithsonite, calamine, and hydrozincite, but these do not form important orebodies in Canada. Their commonly white colour is occasionally helpful in calling attention to sphalerite deposits.

Deposits

Most of the zinc produced in Canada is obtained from strata-bound deposits in which zinc is a co-product of lead or copper, or both; veins and other types of transgressive deposits containing zinc and other metals have supplied important, but relatively minor, amounts. In 1966 about 40 per cent of Canadian zinc was produced from deposits in the Canadian Shield, which contained copper, zinc, and other metals in various proportions. These deposits are mainly in the Timmins–Noranda–Matagami region of Ontario and Quebec, the Manitouwadge area of Ontario, and the Flin Flon region of Manitoba and Saskatchewan. Most are massive sulphide deposits enclosed in and concordant with altered volcanic and sedimentary strata. Several large strata-bound deposits at Bathurst, N.B., and elsewhere in the Appalachian region contain zinc, lead, and copper. Although zinc predominates in some of the deposits of the Shield the only examples described further in this chapter are, for convenience, included in the notes on copper. The strata-bound deposits of western Canada are mainly lead–zinc or zinc–lead types. Leading examples are the Sullivan, described in the notes on lead, and the Pine Point deposits described briefly below. Veins, replacements and other transgressive deposits occurring in various regions contain sphalerite, galena and, commonly, silver minerals.

Pine Point Deposits

The orebodies near Pine Point are in flat-lying Middle Devonian dolomite which is coarsely crystalline, porous, and formed largely of coral. They belong to the general Mississippi Valley class which, because of their economic value, have been studied in great detail without positive proof of whether they were leached from and redeposited in the carbonate sediments in which they occur, or were deposited from igneous rocks that do not reach the surface in the neighbourhood. The details of the origin of the Pine Point deposits remain to be explained, but the evidence obtained thus far favours the opinion that they are replacements and cavity-fillings that are not syngenetic or of biological origin related to the coral, but were deposited from a distant source that may have been in the sediments as a whole or may have been introduced still more distantly. Some of the minerals are stated to be of kinds that could have been deposited only by solutions warmer than surface waters, but this warming may have been caused by the downward circulation of groundwater. The reefs were important in providing suitable environment for deposition. The faults may have caused scarps that facilitated reef formation, and may also have provided channels for ore-forming solutions. Regardless of the ultimate origin, knowledge of the reefs and faults is useful in the exploration of known deposits and the search for additional ones. Reserves were reported in 1966 to be 37,500,000 tons averaging 6.8 per cent zinc and 2.9 per cent lead.

Bathurst Deposits

Magnetite deposits have been known for many years to occur in the Bathurst area of New Brunswick; a relatively small amount of iron was produced from them between 1910 and 1915. Prospecting in the area was retarded by extensive overburden. Drilling to test magnetic anomalies indicated zinc–lead–copper deposits in 1952. This caused further geophysical and geological investigations and, in places, geochemical studies. As a result five mines are now in production. Of these, the Brunswick No. 6 is considered to have been found mainly by geophysical methods, with supporting conventional, geological and geophysical methods; the Brunswick No. 12 is considered to have been essentially a geophysical discovery, with supporting geological studies; the Heath Steele is regarded as entirely a geophysical discovery; the Nigadoo is attributed partly to conventional prospecting and partly to a geochemical survey; and the Wedge, which contains mainly copper, is regarded as a geological discovery.

The deposits are fine-grained mixtures of sulphide minerals, mainly in metamorphosed sedimentary rocks, iron-formation, and schists of Ordovician and Silurian ages. They are interlayered with volcanic rocks and contain bodies of gabbroic to granitic compositions. Most deposits are overlain by thick gossans in which some supergene enrichment has taken place.

Outlook

Canadian zinc mine production rose by 24 per cent in 1965 and by 15 per cent in 1966. The reserves of ore contributed by recent developments in the Timmins and Pine Point areas, and elsewhere, indicate that there is no urgency regarding prospecting for zinc. In 1967 and 1968, there were signs of possible oversupply, but zinc's important place in industry and the research being carried on for improved applications should make discoveries of reasonable size and content attractive on a long-term basis. Some

uses for zinc are, however, being challenged by plastics. Prospecting for zinc will almost certainly be combined with searching for nonferrous metals in general.

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ZIRCONIUM

Zirconium is especially resistant to heat and corrosion. It is desirable for use in certain components of atomic reactors and for other specialized purposes. Therefore the possibility of finding economic deposits in Canada is worthy of some attention, although zirconium is not in short supply on the world markets. Such a source might be as a co-product or by-product.

The principal ore mineral is zircon (zirconium silicate) which, although widely distributed in small quantities as an accessory mineral in granitic rocks and pegmatites, has not been found in commercial amounts in Canada and is produced in a few countries only. It is mined from beach placer deposits, which also contain ilmenite, rutile, and monazite, in Australia and the United States. The most likely places to examine are therefore beach and stream deposits. As some specimens of zircon are fluorescent, this property might assist in detecting and evaluating occurrences.

Zirconium is also produced in Brazil from a variety of baddeleyite (zirconium oxide) which occurs in pebbles of nepheline syenite.

Anyone interested in the possibilities of finding a workable zirconium deposit should realize that innumerable occurrences are known where it is possible to obtain specimens of zircon and what seem to be significant analyses from selected samples. A search would have to be made for exceptional deposits. The price for zircon concentrates containing 65 per cent zirconium oxide in the United States was $70 a ton early in 1968.



16 placer and small-scale lode mining

PLACERS

As was the case in most countries, the first important mining in Canada was placer mining for gold, which reached its peak about the end of the last century. Since then no important new placer districts have been found, although additional productive deposits have been discovered from time to time in known placer districts in the Cordilleran region. Other workable deposits may be found in some of these districts, and some known occurrences that could not be exploited before may become workable in the future. Furthermore, new placer districts containing economic deposits of gold or other minerals may be found, although the widespread search for gold that went on during the great periods of placer mining has naturally reduced the chance for finding gold placers workable at the current price. Therefore, although prospecting and mining are now chiefly concerned with lode deposits, a few prospectors still specialize in placers. All prospectors should be acquainted with the basic principles of placer mining, and should not neglect the possibility of locating worthwhile placer deposits if the territory is favourable.

The subject of placer (alluvial) deposits is extensive, and a large literature is available for those who wish to specialize. The following pages treat the subject more fully than was appropriate in the general chapter on mineral deposits (Chapter 4). They include brief accounts of the history and distribution of the principal Canadian placer districts, and short descriptions of the methods of prospecting, testing, and mining, particularly those applicable to prospecting by individuals and to small-scale mining methods. Companies interested in initiating new placer operations would do well to consult engineers and geologists specially experienced in various phases of placers and placer mining. The following sections refer mainly to gold placers, but much of what is said is applicable to concentrations of other heavy minerals if they should be found in workable quantities.

Origin and Types of Placers

Placers are deposits of sand, gravel, or related material containing particles of gold or other valuable heavy minerals. Gold was and is the most important placer mineral in Canada. Platinum has been found with gold in the placers of the Tulameen district and at a few other places in British Columbia and in the Yukon, but generally not in paying quantities. Most of the platinum was recovered in early days of mining when the price of this metal was low.

Three conditions are necessary as a rule to form commercial placers: (1) occurrence of valuable mineral nearby; (2) release of this mineral from the bedrock by weathering; and (3) its concentration by stream or wave action. Residual placers may be formed by the weathering in place of mineral deposits, but are rare. Most rich placers are concentrations from large volumes of rock occurring in regions that were first uplifted, then dissected by streams, and later worn down for many thousands of feet to terrains of relatively low relief. As placers containing gold are the only deposits of this type of great importance in Canada the following account refers to them.

The occurrence of placers in any region may or may not indicate that workable lode deposits occur in the region. For example, both placer and lode mining for gold have been successful in the Cariboo district of British Columbia. On the other hand, the gold in some placer districts may have existed in the oxidized upper parts of sulphide deposits or in veins that were entirely removed by erosion, or the remnants may be too small to mine. No important lode gold deposits have been found, for example, in the Klondike, where the placer gold was derived from gold-bearing quartz veins; the remnants of these so far discovered have not been worth working. The great quantities of quartz-rich gravels produced by erosion of soft rock containing scattered veins show that many cubic miles of bedrock have been eroded from the region. Some of the gold in residual placers may have been formed by deposition from solution, but nuggets in stream gravels do not appear to have formed in this way. Most nuggets are well water-worn, and the gold crystals and unworn fragments that are occasionally found in some placers were doubtless protected by burial or were released from their enclosing matrix shortly before being found.

The distribution of gold in placers is irregular. Coarse gold, commonly accompanied by some fine or moderately coarse gold, may be scattered through the lower 10 or 15 feet of gravels, especially if they contain much clay or other fine material, but is generally concentrated on or near the bedrock. Paystreaks may occur at any elevation in a gravel deposit on a false bedrock of clay or other impervious bed. They may or may not occupy the deepest part of a stream channel. Pay gravel may occupy the whole width of the stream bottom in narrow, V-shaped valleys; in broad, flat-bottomed valleys the paystreak is likely to be much narrower than the valley floor and its course may be quite different from that of the present stream. Most paystreaks in broad valleys were originally formed in narrow valleys of fairly high gradients. As the gradient became less and the valley was widened by the meandering stream, the paystreak was buried beneath alluvium. A stream of low gradient tends to meander and the bends tend to move downstream, so that the materials in the valley bottom are reworked many times by the stream. A paystreak may be shifted in location by this process of reworking by the

stream, or, if the deposit consists of coarse material or becomes somewhat cemented or hardened after the shifting of the stream, it may remain in its original position. Paystreaks are not continuous and may split or terminate abruptly, because gold is concentrated chiefly at such places as the inside of bends, where alternate deposition and erosion take place and where the bedrock forms good 'riffles'. Uplift or some other geological event may cause the stream to deepen its valley, and the old paystreak, depending on its location, may then descend into the new valley or remain in its original position to form a bench or old-channel placer. Barren ground may occur, therefore, in the bottom of the present stream valley in the stretches that are bordered by one or more rock benches, and exceptionally rich ground may occur where the stream has cut down beneath the old channel.

Pot-holes and other depressions in the bedrock of a stream rarely contain gold. They are formed by erosion and any gold carried into them by the stream is likely to be ground fine by the action of current-transported sand and gravel and to be washed out. Gold does not occur in payable quantities in the submerged parts of deltas. Some gold may occur in alluvial fans that frequently form the upper parts of deltas, but only fine gold can occur in fans and there is little opportunity for its concentration into paystreaks because of frequent shifting of the stream channels.

Flood (bar or very fine) gold is sufficiently fine or flaky to be transported in muddy water. The particles range in size from a few to several thousand 'colours' to the cent. In regions where fine gold is supplied to the streams by erosion of their banks or beds, paystreaks may occur in the bars and banks of the streams. The paystreaks as a rule are only a few inches to a foot or 2 feet thick and lie at or near the surface between extreme low-water and high-water marks, in places (as on the upstream side of bars) where conditions are favourable for alternate deposition and erosion of material transported by the stream. They may occur in bench deposits at various elevations above the streams. As erosion and deposition go on from year to year the bars shift downstream; old paystreaks are destroyed and new ones are formed, but at a very slow rate. The rich flood gold deposits mined in the early days on the Fraser and on other streams in Canada represented the concentration of gold by these streams in post-Glacial time. The placer deposits of the Saskatchewan and Athabasca Rivers, in Alberta, as well as most of those along the Fraser, Stikine, and Columbia Rivers in British Columbia, are of this type. Many of the richer bars on these streams have been worked several times. The first harvest, of course, was the richest and the work in recent years has rarely paid. Very little gold occurs below extreme low water in stream valleys containing flood gold deposits with no coarse or moderately coarse gold, and the flood-gold paystreaks are thin and discontinuous. Many attempts at placer mining on a large scale by dredging and by other methods on such streams (for example, the Fraser) did not succeed owing to failure to recognize the character of the paystreak or to inadequate testing of the ground.

Gravel-plain placers are formed in broad valleys or alluvial plains containing gravels that have been repeatedly re-worked by meandering streams or by streams of fairly high gradients that tend to shift their channels. The gold is derived by erosion of the banks and the land at the headwaters of the streams, and is likely to be moderately fine and fairly evenly distributed through the gravels. Such placers are best developed in unglaciated areas, but occur on a small scale in glaciated regions, for example, at a few places in Cariboo district, British Columbia. They can be profitably mined as a rule only by dredging.

Glacial gravels may contain gold, but have little economic value unless they have been re-concentrated by stream action or have been derived in part by erosion of pre-existing placers. Glacial erosion is more likely to disperse earlier placers than to form concentrations of heavy minerals. Moraines, kames, eskers, and glacial outwash plains have not proved to contain gold in paying quantities. Scattered pieces of gold and isolated masses of gold-bearing gravels may occur in boulder clay. Stratified glacial silt and clay contain no gold. Interglacial paystreaks formed by normal stream erosion during a long interval between periods of glacial advance may occur in glaciated regions, in a place sheltered from the scouring of later glaciation. Much of the gold found in glacial gravels is moderately coarse and fairly uniform in size, as if sorted by powerful streams. The re-sorted glacial gravel placers of the old placer mining regions of British Columbia and of Beauceville district, Quebec, have been mined chiefly by hydraulicking and could rarely be mined profitably in any other way.

Buried placers are paystreaks that are covered with later deposits of glacial drift, lavas, and tuffs, or barren alluvium. Gold-bearing gravels, buried beneath great or small thicknesses of glacial drift, may occur in the bottoms of valleys or on rock benches and in old stream channels bordering valleys that were not severely glaciated. Such valleys are V-shaped. Rounded, U-shaped valleys are not likely to contain buried paystreaks, because of the effects of glacial erosion. Glacial gravels in the bottoms of such valleys may contain some gold, but the pay is generally so scattered that it cannot be mined profitably. Most of the rich paystreaks mined in the early days in the Cariboo and in other districts in British Columbia were buried beneath glacial drift and were mined chiefly by drifting (tunnelling). Lava-buried placers have been found in only a few places in Canada, as at Ruby Creek in Atlin district, but other occurrences may be found in British Columbia and Yukon Territory. The rising of the base-level of erosion, or overloading of streams, may cause deposition of barren alluvium above the pay gravels in a valley bottom. In arctic and sub-arctic regions, as in the Klondike, the ground is permanently frozen and thick deposits of 'muck' commonly overlie the gravels. Muck consists of slightly decomposed organic matter mixed or interbedded with fine sand, silt, and clay. It is formed partly by growth of vegetation in place and by soil creep and partly by deposition from overflowing streams. In places it contains much 'ground ice' or *permafrost*. As muck is a good insulator it prevents thawing of the ground

during the summer. Ground from which the muck has been removed by hydraulicking or by some other method thaws naturally to depths of 10 to 30 feet in three or four years.

Beach placers are formed by wave erosion and concentration of the materials in sea cliffs. Rich beach placers generally occur only in places where stream or residual placers are eroded by waves. No important gold-bearing beach placers are known along the coasts of Canada, nor do they seem likely to be found, except possibly locally, because much of the material eroded by wave action is glacial drift. Beach sands containing magnetite have been found in places along the Pacific coast and the north shore of the Gulf of St. Lawrence.

Placers in the glaciated parts of Canada differ from those in the unglaciated parts of the Yukon in several ways that affect their mining possibilities. The presence of large boulders in some placers in the glaciated areas renders the deposits workable only by the heaviest types of mechanical equipment. Bedrock in glaciated areas is likely to be hard and unweathered and this may make more difficult the recovery of all the gold by dredging, although modern dredges used in the Klondike successfully overcame this where the rock was jointed. Large boulders are absent and there is no overburden of glacial drift in the placers of the unglaciated parts of the Yukon. There are thick deposits of muck, however, and thawing of the ground is necessary in mining operations.

The most favourable areas in Canada for prospecting for placers probably are any parts of the Yukon and northern British Columbia that may not have been prospected exhaustively. Unglaciated areas in which mineral-bearing igneous or metamorphic rocks occur, at least to some extent, are the most favourable. In glaciated areas narrow, V-shaped valleys, preferably those bordered by rock benches, should be sought, and rounded, severely glaciated valleys avoided. Valleys that were only slightly glaciated usually lie transverse to the general direction of glacial ice movement and do not head in glacial cirques.

From a study of placers in eastern Siberia Gorbunov concluded that the gold had been moved mainly vertically as a result of long erosion of lodes, and that horizontal distances between areas of maximum concentration and lode or earlier placer sources could be determined. The methods might be applicable to prospecting for gold or other alluvial minerals under Canadian conditions, with due allowance for glaciation, permafrost and valley gradients; such prospecting might be undertaken to search for lodes from which known placers were derived, or to search for workable placers in the vicinity or region of known lodes.

Historical Notes

Placer mining usually takes place early in the development of a country because the more obvious placers are relatively easy to find and to mine. Fairly inexperienced persons can learn to find them by searching the beds and banks of streams, and the richer and less deeply buried ones can be mined with a few simple tools and contrivances. For example, the Greek legend of Jason and the Golden Fleece is based on the early practice of using sheep skins for catching fine grains of gold.

The first important placer discovery in Canada was in the basin of the Chaudiere River southeast of Quebec city. Extensive mining did not begin there until 1875, although the first minor discovery was made in 1823. Gold to the value of about $2 million was obtained between 1875 and 1885, when about five hundred miners were at work; after 1885 the yield declined. There may still be buried deposits in this and in similar regions, but the possibility of finding and working them is made difficult by the amount of overburden, the number of large boulders, and the low gradients of the streams, which make it difficult to sluice the gravels. The operations in this part of Quebec were the only significant placer mines in eastern Canada. A few low-grade occurrences of gold and other minerals have been found in other parts of eastern Canada, but they have not been successfully exploited. The widespread and intense glaciation to which most of Canada was subjected seems to have destroyed most of any rich placers that may have existed in Tertiary times. The possibility of finding workable placers in eastern Canada should not be overlooked, but the chances seem to lie mainly in the possibility of working, at some future date, certain sands and gravels for valuable residual minerals other than gold if the demand for them should make this worth-while and if economical methods can be evolved.

Canada's great placer fields were in the Cordilleran region. They were found as a result of the northward spreading of prospectors after the rich discoveries of placer gold in California, which began in 1849. Some placer gold had been found earlier in what is now British Columbia, the first significant discovery having been in 1857, at Nicoamen on the Thompson River, a tributary of the Fraser. News of this caused a great influx of miners from California and elsewhere, and discovery after discovery was made along the Fraser and its tributaries. By 1860 the vanguard had reached the Cariboo region, where much richer deposits were found, thus initiating the great Cariboo gold rush that brought miners and adventurers from many countries. The total production from the Cariboo placers is estimated to have exceeded $50 million; production was at its peak from 1860 to 1863, after which it gradually declined, although a little placer mining is still carried on in the region.

From the Cariboo, prospectors pressed northward and found important placers in the Omineca, Cassiar, and Atlin regions, where some placer mining still goes on. Then they penetrated Yukon Territory, where the discovery of gold on Bonanza Creek, a tributary of the Klondike River, in 1896 heralded the greatest gold rush of all. Production here reached its peak in 1900, when the output was valued at $22 million for the year. Value of total production from the Klondike to the time of writing is more than $200 million. Several minor placer fields were found in the Yukon outside the Klondike area. As in the Cariboo and other regions, the early work was done by individuals and

small partnerships, mining along the banks of streams or probing ancient stream channels with shafts and tunnels driven in the gravels and supported by timbering. The Klondike region is one of the few parts of Canada that was not glaciated, and was thus favourable for the occurrence of rich placers. It is significant to note that the relatively small unglaciated area in Yukon Territory has yielded nearly three times as much placer gold as has the remainder of Canada, which was glaciated.

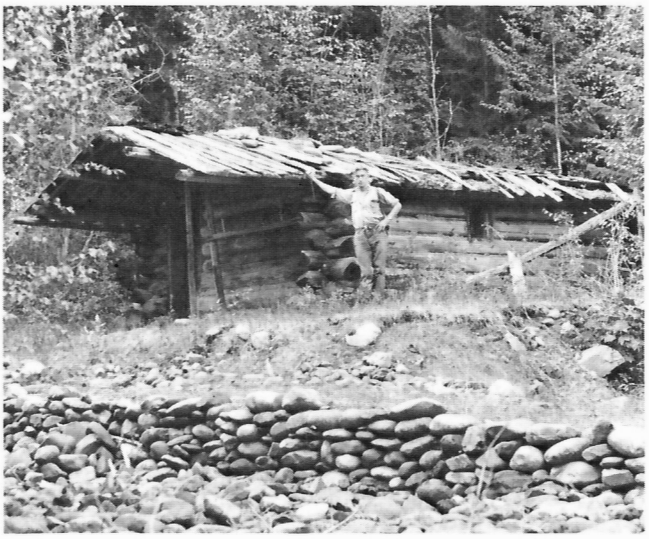
The gravels of the Klondike were permanently frozen and had to be thawed by lighting fires, but this was an advantage to the early miners because shafts could be sunk to bedrock without pumping, and it is still an advantage in Keystone drilling. In later years mining was done mainly by large companies using dredging and hydraulic methods and extensive special thawing equipment, but some small-scale placer mining continues.

The Peace and North Saskatchewan Rivers in British Columbia and Alberta are the only other places in western Canada where placer mining has been done to any extent. A relatively small amount of fine-grained gold has been and still is being obtained along these rivers. The Peace River gold may have worked its way down from tributaries in the interior of British Columbia where lodes are known to occur, or it may have been reconcentrated from glacier gravels that included particles of gold weathered from deposits in the Canadian Shield. The gold of the North Saskatchewan apparently came from the erosion of sedimentary rocks that contain slight amounts of gold.

After the heyday of the Klondike, placer production declined. Impetus was given to placer mining in western Canada during the depression that began in 1930, because gold was in great demand, because its price was raised, and because unemployed men could make a dollar or two a day by gleaning along many streams that would not warrant commercial placer operations. This ended with the beginning of World War II, and since then interest in placers has been at a low ebb, because most of the known higher grade workable deposits have been exhausted, and rising costs have made lower grade deposits less attractive. However, after 1950 improved machinery allowed greater yardages to be handled by fewer men, and there was a noticeable revival in some camps in northern British Columbia and the Yukon. In 1966 the large dredging operations in the Yukon ceased. In that year there were about twenty-two smaller operations in the Yukon and forty in British Columbia.

Great as was the production of gold from placers in the Cordilleran region, this was not as important as the indirect effects. Before the discovery of gold in what later became British Columbia the region was in the hands of a few fur traders. The gold discoveries brought it worldwide attention and a great influx of people. Many of those who came seeking placer wealth turned soon to lode prospecting, to agriculture, and to business of various kinds. Roads and railways were built, and towns and cities were established. The story of the gold rushes is the epic of western Canada.

The only significant production of metals other than gold from Canadian placers was about 10,000 ounces of platinum that accompanied gold in placers on the Tulameen River in southern British Columbia, and tungsten recovered from Canadian Creek and Dublin Gulch during both World Wars. Considerable tin is said to have been discarded during early operations in the Klondike. Boulders of jade are recovered as a by-product of some gold placer operations. Increasing attention should be paid to the possibility of recovering minerals as by-products from any substantial placer operations if they are undertaken in future.



C. E. Cairnes 74059

Plate 78. Site of early small-scale placer operation, British Columbia. Note boulders moved and piled by hand to permit reaching gold, probably for recovery by a rocker or by shovelling into a sluice-box.

Methods of Prospecting for Placers

The principal placer region of Canada, particularly for gold, is the interior belt that extends through central British Columbia, flanked on the east by the Rocky Mountains and on the west by the Coast Mountains, and which continues into the central part of Yukon Territory and on into Alaska. Not only does this large area, composed of plateaux and fairly ancient mountains, contain many lodes whose weathering provided the gold and other minerals that became concentrated in placers, but the topography was suitable for placers to accumulate and, largely, to withstand the effects of glaciation. Some placers formed in Tertiary time were preserved as old channels covered by glacial debris or lava; others were scoured out by the glaciers, their gold was incorporated in glacial drift, and later was reworked and re-concentrated by interglacial or modern streams. Parts of British Columbia and the Yukon are therefore the most favourable places in which to seek placers, but it must be emphasized that they have already been searched intensely.

The usual method of prospecting for placers is to follow creeks and rivers panning material from bars, patches of sand and gravel in stream beds, and gravel banks, particularly the lower gravels near bedrock. Most creeks have been

tested in this way already but there are chances of finding places that were missed, or places that were worked by primitive methods and that would warrant hydraulicking or dredging, or others that were too lean to be worked formerly, or that could not be worked until the advent of modern machinery such as bulldozers, boulder hoists, and electric pumps. Even if only a few colours of gold are found in this way, they may lead to more, so the prospector keeps panning, and if he can no longer obtain traces, he backtracks and tries another tributary or bank in the hope of finding a workable deposit. In prospecting streams containing moss-covered boulders, the moss should be scraped off and panned, because particles of heavy minerals may lodge in it.

Buried channels may be postulated from a theory of the former location of the course of a stream, or from a study of the topography as shown on a map or air photograph. It is, however, difficult for an ordinary prospector to check such a theory if overburden is deep. Companies may do so by drilling places suggested by geological, geophysical, or geochemical evidence. Speculations regarding buried channels have to be considered with caution because testing them is expensive. In the old placer areas there are frequent rumours about the presence of old channels, and attempts are sometimes made to induce persons to finance work to trace them. Some of these efforts are well founded, but all such ventures should be guided by the opinion of a reliable placer engineer or geologist. Attempts to trace or discover placers by magnetometer surveys based on the common association of gold and magnetite have generally been unsatisfactory because magnetite with little or no gold is widely distributed.

The gold pan, whose use dates from ancient times, is an indispensable aid in prospecting for placers, in testing placer ground, and sometimes for the final 'cleaning up' of gold recovered from placer mining. Like almost all methods of recovering the valuable minerals in placers, the basis of panning is that the material to be recovered is considerably heavier than the worthless grains of sand and other material that are to be discarded. Many think that the pan is the means of actually mining placers, but its use is too slow except where exceptionally rich placers are concerned. The pan is also very useful in connection with prospecting for lodes and testing crushed samples from lodes. Nearly all prospectors will benefit from learning the art of panning, which can be mastered with a little practice.

Gold pans are of different sizes, the most common being 16 inches in diameter at the top, the sides sloping at about 40 degrees, and the depth being about 2½ inches. They are generally made of sheet iron. If they are too highly polished, or if they become greasy, they will not retain fine-grained gold; new ones may have been greased to prevent rusting.

The pan is filled with sand or gravel and immersed in a slack part of a stream, or in a lake or pond, or even in a tub of water, and the gravel is stirred with the hands. Any soil is thus washed away, after which any larger pebbles are tossed out by hand. The pan is then alternately shaken, and rotated under water, then raised to the surface at an angle so that the upper material is spilled and washed away. This process is repeated until only the heavier grains, if any, remain. These generally comprise magnetite, pyrite, hematite, and other heavy minerals, and any gold that may be present. If a little water is added and the pan is rotated with a deft movement, the gold, being heavier, is separated to form a 'tail' behind the other heavy minerals. The gold may include nuggets, or pieces about the size of grains of wheat, but it is usually in the form of small flakes or grains called 'colours'. Beginners often become excited if they see a few colours as a result of their panning, but these colours are so small that their value is slight. To save the gold in the pan, the heavy fraction is dried, magnetite is removed with a magnet, and other foreign grains are blown out, picked out, or allowed to remain. Very fine gold may have to be saved by panning with a copper pan and placing a little mercury in it to form an amalgam, which is heated in a retort to drive off the mercury and condense it for further use. Care must be taken not to breathe the poisonous mercury fumes.

Like many arts, panning cannot be learned merely by reading about it. It is best to obtain instructions from an experienced person, but if this is not possible the learner should practise along the shore of a stream or lake, or even in a tub of water. The gravel used for practice does not need to contain placer minerals; a small specimen of a heavy mineral can be crushed and added to the gravel, or if nothing else is available iron filings could be used. Practice should be continued until the exact amount of heavy grains can be separated and retained in the pan.

Testing Placer Ground

No major placer operation should be undertaken until careful testing of the deposit, under the supervision of a qualified and reliable man, has shown sufficient material and content to exist under mineable conditions. Many large projects undertaken several years ago failed because inadequate testing of the ground led to a too-optimistic opinion of the gold content.

For deposits that are not too deeply buried, the usual method of testing is to dig pits at regular distances, to measure in cubic yards the amount of gravel removed, and to treat this removed material, or the part that constitutes the paystreak, by panning or with a rocker. The gold or other mineral recovered is weighed. The average is calculated from the recovery from each pit, and the value of the deposit is expressed as a certain number of cubic yards averaging so many pennyweights or ounces of gold to the yard. It is commonly considered that a particle or 'colour' of gold large enough to make a sound that can be heard when dropped onto an empty gold pan is worth about 1 cent; and that gold to the value of 1 cent in a panful of gravel (standard size pan) is the equivalent of about $1.30 per cubic yard of gravel.

For deeper deposits, it is customary to drill holes at regular intervals by means of Keystone or other drills, as described in the section dealing with the exploration of lodes. The sand or gravel pumped out of the drill-hole is panned or rocked to permit weighing the amount of gold

in it, and the value per yard is estimated from this weight and the cubic content of the drill-hole in the paystreak.

In estimating the value of placer ground for mining it is important to determine the type to which the deposit belongs, for certain kinds of deposits, as outlined above, require much more testing than others to determine their value. Each type of deposit can generally be mined profitably by one or two methods only. It may be that certain kinds (for example, bar deposits) can be mined profitably only by hand methods. Preliminary testing of the ground may be done by panning (estimating 150 pans to the cubic yard), or by sinking test pits or shafts. Channel samples from the faces of the pits or shafts or, preferably, all the material excavated, are then tested by panning or 'rocking', as explained below. The material excavated swells in volume, usually increasing by about 50 per cent.

The most efficient means of testing placer ground is by drilling. This was generally done formerly by Keystone drills but some of the other forms developed recently for other purposes may be suitable. As the Keystone drill cuts a somewhat larger hole than the outside diameter of the casing it is necessary to allow for this in estimating the volume of materials removed in drilling. One method of doing this is to consider that the value of gravel per cubic yard is the value of the gold obtained, multiplied by 100, and divided by the depth of the hole in feet. This is on the assumption that 100 linear feet of 6-inch hole (the size of casing ordinarily used is 6 inches) has a volume of 1 cubic yard. Thus the formula is:

$$\text{value of gravel per cu. yd.} = \frac{\text{value of gold obtained x 100}}{\text{depth of hole in feet}}$$

When drilling has been carefully done, 75 per cent or more of the estimated yield can be recovered by dredging. This includes all losses, not only those in the tailings, but unrecoverable 'islands' and corners left behind in the course of operation. The recovery of the gold in hydraulicking may be greater or less than 75 per cent, depending on whether the bedrock can be reached and how thoroughly it can be cleaned.



R. Skinner 200843A

Plate 79. Placer mining with power-shovel, sluice-box, and bulldozer to clear tailings, Yukon Territory.

Small-scale Placer Mining Methods

In former years many placers were worked for gold by individuals or partnerships of miners because elaborate equipment was not needed. Picks, shovels, axes, whipsaws, and perhaps wheels for making wheelbarrows were about all the tools required. There may still be some opportunities for this kind of mining, apparently almost exclusively in British Columbia and the Yukon.

In the simplest operations gravel is shovelled from the bed of a stream or from a bank and placed directly in the gold-saving device, large boulders being rolled aside or stacked. Such piles of boulders can be seen in many places along western streams, marking the sites of early placer mining (*see* Pl. 78).

Another simple method, practical in some cases, is to sluice overburden or gold-bearing gravel by diverting a stream or part of it. If the amount of water is small, it is sometimes impounded and released periodically in the method called 'booming' (*see* Pl. 70), as explained in connection with the exploration of lodes.

One of the most common methods, called 'hydraulicking', consists of forcing water under pressure to cut away banks of gravel (*see* Pl. 80). This is mainly a large-scale operation, but is sometimes practical for small operations, either by using pumps, hoses, and nozzles, or by diverting water from a stream into a ditch sufficiently high above the placer to form a 'head'. The ditch discharges into a pipeline, at the end of which is a large nozzle called a 'monitor' or 'giant'; in small operations the diameter of the end of the monitor would be 1 inch to 4 inches. Pressures should not be more than 60 to 100 pounds per square inch, depending on the equipment, as higher pressures are less satisfactory and may be dangerous. When overburden is removed it may simply be allowed to flow away with the water discharged by the nozzle or monitor, but gold-bearing gravel or overburden that cannot be separated from it is sluiced into the gold-saving equipment, which is generally a line of 'sluice-boxes' (*see* Pls. 81 A and B). To accomplish this, water may simply be allowed to flow through the pit as a ground sluice, or the nozzle or monitor may be turned in the required direction from time to time, or a separate

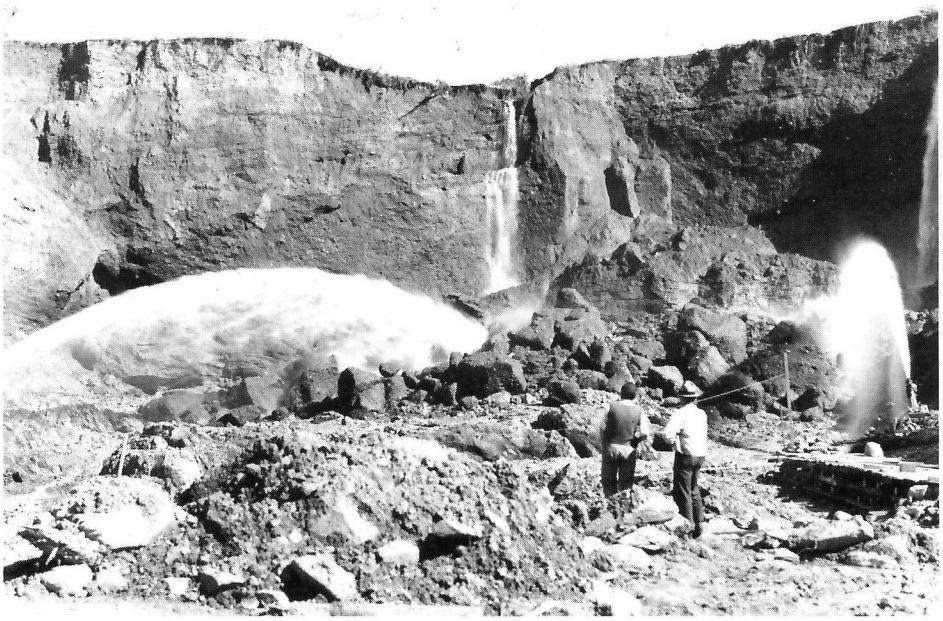


Plate 80
A large hydraulic mine in British Columbia. Note two ground sluices in background, cutting into the bank to hasten its disintegration. Water from monitor at left is cutting the base of the bank, and that from monitor at right is breaking up large chunks of gravel that have fallen into the pit. The 'pay gravel' is on bedrock at the base of the pit. The water from the monitors drains the gravel into sluice-boxes that are not visible.

A. H. Lang 89572



H. S. Bostock 88546

Plate 81A. Sluice-box with transverse riffles.



H. S. Bostock 88563

Plate 81B. Sluice-box with longitudinal riffles.

monitor may be required. It is often necessary to go over the bedrock exposed by sluicing or by hydraulicking, to pick up by hand or with tweezers gold lodged in crevices.

Buried channels that cannot be exposed by hydraulicking or other methods are mined by 'drifting' if rich enough to warrant it. This is done by tunnelling in the gravel, and supporting the opening by poles or boards called 'lagging', held in place by timber posts and cross-pieces. This is a dangerous procedure unless done skillfully. The opening may be begun either by driving directly into a bank or by sinking a shaft in overburden or sometimes in the rock rim of a valley. The drift is run on a slight incline to permit drainage, and gravel is usually removed with a wheelbarrow or a small mine-car on a track. Large boulders are often rolled aside into underground openings to avoid having to bring them to the surface. Much of the early mining in the Klondike was done by drifting. Because most of the ground remained frozen even in summer, the mining was done after thawing, by use of fire, or more often steam points, and the gravel was stockpiled until summer, when it could be treated in sluice-boxes.

Nowadays operations of moderate size may be worked by a few men with fairly expensive equipment, by using power shovels, draglines, bulldozers, mechanical loaders, or suction dredges to remove overburden and to mine gravel in places where hydraulicking or other methods are not practical. The gold-saving equipment may be skidded from place to place as required, or carried on a barge that floats in a water-filled pit, after the fashion of a dredge. Some firms manufacture portable small-scale equipment for testing or working placers. Some persons use such equipment as a hobby.

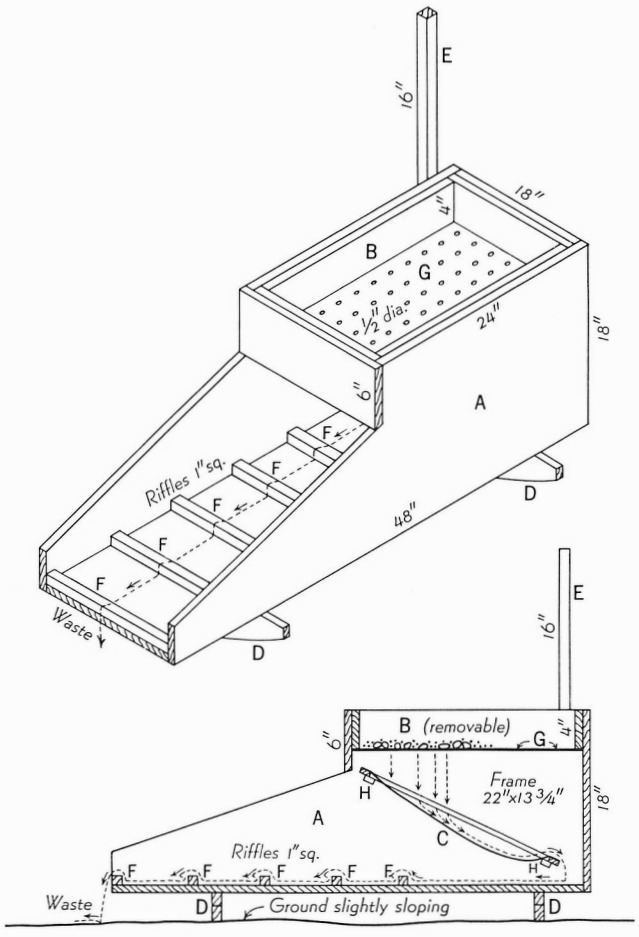
Large-scale Methods

Large placer deposits are operated by companies using large hydraulic or dredging equipment or underground

mining methods. These are beyond the scope of a book on prospecting, except that prospectors might be able to interest companies in acquiring a large placer discovery.

Equipment for Recovering Placer Minerals

A common device for separating the gold obtained in small operations, called a rocker, is somewhat the size and shape of a cradle. One can be made from a few pieces of board, a piece of coarse screen or sheet iron with holes drilled or punched in it, and a piece of canvas, burlap, blanket, or some other cloth having a nap, which is necessary to catch fine gold. Rockers are of slightly different designs and sizes, the larger ones being used when most of the gold is fine grained, because the longer box is then more efficient. A medium-sized one is illustrated on Figure 40.



A. *Box, 48"x18"x18".* B. *Tray with iron bottom containing ½" holes.* C. *Apron of burlap mounted in frame.* D. *Rockers.* E. *Handle for rocking.* F. *Riffles, for catching gold.* G. *½" holes in iron bottom of tray.* H. *Cleats holding frame in place.* ----→ *Course of material through rocker.*

Dirt and water are put into B *and apparatus is rocked by handle. Water and sand and gold pass through holes onto apron* C *where most black sand and gold is caught, then over riffles by which more gold is caught, thence to waste. Material remaining in* B *is thrown out and apron is removed and washed.*

Figure 40. Diagram illustrating construction and mode of operation of a rocker (after J. D. Galloway).

To operate a rocker, gravel is shovelled onto the screen. Water is then poured over it from a dipper and at the same time the rocker is given a quick jerk with a sudden stop. This is repeated, with the addition of just enough water to wash the sand through without flushing out any fine gold. The coarse material that does not pass through the screen is thrown out, after removing any nuggets that might be present. A rocker is most efficient when used by two men, one of whom shovels in the gravel while the other operates the rocker and the dipper. Water can be saved and used over again if necessary, but clean fresh water is best. Two men can wash 3 to 5 cubic yards of gravel a day in this way, which is ten to twenty times as much as they could do by panning.

The commonest method of saving gold is by one or more sluice-boxes, which are wooden flumes or troughs through which water is made to flow (*see* Pls. 81 A and B). The gravel may be shovelled in, or dumped mechanically or from a wheelbarrow at the top of the box or line of boxes, or it may be washed in by ground sluicing or hydraulicking. The boxes are usually 8 feet long and 12 inches in width and depth, but smaller ones are sometimes seen. They are placed on the ground or on trestles or



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Plate 82. Sluice-box at large placer mine in B.C. Here forks were used to remove boulders to prevent clogging.

boulders, commonly with a slope of 1 to 10 or 1 to 12, depending on the amount of water and the coarseness of the gold; there should be enough water to half fill the boxes. To catch the gold, the bottoms of the boxes have movable riffles placed crosswise or longitudinally, or are lined with blocks of wood or cobblestones or expanded metal. Some miners use crosswise riffles made of 2″ by 4″ lumber to which sections of used automobile tires are nailed. Longitudinal riffles made of poles are used sometimes if one or two men wish to make boxes quickly. Canvas, burlap, blankets, or matting may be placed on the bottom of the last box to catch fine gold; the cloth is sometimes covered with a piece of expanded metal.

After a sluice has been operated for several days or weeks, depending on the richness of the placer, supply of water, size and number of boxes, etc., the boxes are 'cleaned up'. The water is turned off, the riffles or blocks, etc. are removed, and a little water is allowed to flow down the boxes to wash the gold and other heavy minerals towards the end of the box. As a rule, there is a section consisting mainly of nuggets or grains of gold, which is brushed into a small scoop and then panned to get rid of unwanted material, and also a concentrate composed mainly of magnetite, other heavy minerals, and some sand and gravel. This is shovelled out and the gold or other valuable minerals are separated by panning or rocking. Very fine gold may have to be recovered by amalgamation with mercury, and if there is much fine gold, mercury may be placed behind the riffles during sluicing, in which case the resulting amalgam is removed during the clean-up. Where mercury has been used in sluice boxes or to separate gold from heavy sands, the amalgam is softened by adding more mercury, and the material is then stirred so as to cause base material to rise to the surface, where it can be skimmed off. The amalgam is then placed in a bag of chamois skin or closely woven cotton cloth, and the excess mercury is removed by squeezing it through the bag. The mercury is then driven off by heat, leaving the gold, the operation being preferably performed in a retort, which makes it possible to recover the mercury by condensing it in water, or by simply heating on a shovel. In any event, as mercury is very poisonous, the heating should be done in the open or in a well-ventilated place, and the hands should be brought into contact with the metal as little as possible, and should be well washed as soon as the operation is completed.

Other methods used for saving gold under particular conditions in small operations, such as 'long toms', 'undercurrents', and mechanical and magnetic separators, are described in more detailed publications.

In large hydraulic operations, the method of recovery usually consists of a long line of large sluice boxes, which often have at the bottom round wooden blocks sawn from logs. If the concentrates require the use of much mercury, the amalgamation may be done in a rotating metal drum called an amalgamation barrel.

The gold-washing plants used in connection with dragline operations, dredges, etc., may consist merely of sluice boxes arranged in a zig-zag manner to save space, or they may contain mechanical equipment such as revolving screens, shaking screens, or vibrating tables. An efficient device for some kinds of placer operations consists of a battery of metal troughs in spiral shape. As water carrying mineral grains descends the spiral, centrifugal force separates the heavier grains.

The Possibilities in Prospecting for Placers

Interest in placers has been declining for many years, and the outlook is certainly in favour of lode rather than placer prospecting. There are, however, possibilities of finding workable placers, particularly for gold and mainly in western Canada, and if gold should ever increase in value some deposits too poor to be worked at present might become workable. In any future placer operations for gold, it would be well to consider also the possibility of recovering other valuable minerals. Tin, in particular, and perhaps platinum and tungsten, were discarded in some old placer operations either because they were not recognized or were not thought worth saving. Other concentrations of heavy minerals may yet be found and worked, particularly in the unglaciated part of Yukon Territory and certain lightly glaciated parts of British Columbia and the Yukon.

New demands or increased prices for certain minerals, or improved methods of extracting certain elements from minerals, may at some future time make their recovery from sands and gravels economically feasible and thus initiate types of placer mining that are not practical today. It should be noted, however, that small and unimportant amounts of many minerals can be found in sands and other forms of overburden. The prospector's hopes are often aroused because analyses of such samples show a little of some valuable element, but, as in the case of lode prospecting, the problem is not simply to find occurrences but to find deposits of sufficient size and content to be worked economically.

Suggestions for Additional Reading

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A bulletin containing general information on placer mining in this province, the nature and formation of placers, the principal placer areas of British Columbia, and methods of mining suitable for small-scale operations.

LODE MINING

The actual mining of lode deposits is almost always beyond the scope of the prospector. However, a general knowledge of the mining and treating of ores will help the prospector to decide whether or not a discovery has possibilities. Also, occasionally, it is advantageous to work a lode in partnership. Therefore a short discussion on lode mining in general is included here, and is followed by a short account of small-scale mining methods.

General Principles

Mining on commercial scales, which generally range from one hundred to several thousand tons of ore a day, is a highly organized industry. It employs skilled miners and other tradesmen, professional engineers, geologists, and other scientists, and many forms of machinery and specialized equipment. By these means it is often possible to mine successfully on narrow margins of profit. As in other industries, production costs are often lower in the larger operations, because many fixed expenditures can be spread over a larger volume of output. Hence, it is commonly possible to mine ores of low value if they occur in sufficient quantity to permit an operation in the class of thousands of tons a day, whereas the mining of smaller deposits of similar grade would be uneconomic.

Another important consideration is that many mines contain sections of different grades of ore. Where costs can be reduced or where the price obtained for the product is high, or if more efficient methods of treatment are developed, some of the lower-grade material may become ore. It is usually necessary, therefore, to do a great deal of sampling of the underground exposures and of the ore and rock mined and to prepare careful and detailed sampling plans. This permits close control of mining and adjustment of the average grade of ore to meet the costs and prices pertaining at the time. For these reasons a mine may be operated at a larger tonnage during one period than another, or it may have to be closed entirely during unfavourable periods.

There are two principal methods of working lode deposits: open-pit mining (also called strip mining when large sections are removed), and underground mining.

Open-pit mining is suitable for deposits that are fairly broad and that reach the surface or require the removal of only a reasonable amount of overburden. After any overburden has been stripped away, a pit is opened and the ore or rock is usually blasted down in benches by drilling vertical holes. The material broken is usually loaded by power shovels onto trucks or hoisted in 'skips' on an aerial cable-way. When a flat-lying stratum is worked for building stone the pit is usually called a 'quarry', and when the operation is for ore or minerals to be crushed and treated the pit is usually called an open-cut or open-pit. The term 'glory hole' is generally applied to a large pit connected to underground workings; in such operations the ore from the pit is recovered through the underground workings instead of being hoisted directly from the pit. Large open-pit methods are generally the cheapest ways of mining, and are particularly characteristic of iron and copper mines.

Underground methods are necessary for mining deep orebodies and narrow, steeply dipping ones at or near the surface. If the terrain is suitable, it is more efficient to begin operations from an adit, as explained in connection with the exploration of deposits, but many underground mines must be begun by sinking more costly shafts. Horizontal workings are then driven at appropriate levels, generally at intervals of between 100 and 200 feet. Ore is removed by blasting openings called 'stopes', of which there are different types to suit particular conditions. Workings that will not stand safely of their own accord are supported by timbers or by filling with waste rock, or sand or other material brought from the surface.

Mining operations usually include plants wherein the ore is treated at the property to an almost finished product, such as gold which requires only final refining, or which concentrate the ore to avoid payment of freight on worthless material that can be separated fairly easily. The processes used generally consist of crushing, grinding, and one or more of many different methods of concentrating. Concentrates, and in some cases 'raw' high-grade ore, are then



Plate 83
Breaking, sorting, and sacking high-grade lead-silver ore.

A. H. Lang 79322

usually treated in a smelter, where the material is melted and separated by the draining off of worthless slag, or in a leaching plant in which the valuable constituents are extracted by solution. It is not usually possible to have ores from different mines treated in a common concentrator because the process has to be closely adapted to a particular ore, but some districts contain deposits sufficiently alike to permit the trucking of ore to a common concentrator. Several mines commonly supply one smelter, either in the district or far removed from the mines. Such a smelter may either buy the ore or concentrate outright, or treat it on a fee basis. Concentrators and smelters that treat ores from different mines are often called 'custom' mills and 'custom' smelters.

Small-scale Lode Mining

It cannot be emphasized too strongly that, in general, prospecting and mining are distinct phases of the mineral industry. The prospector usually has neither the finances nor the training and experience necessary to conduct the large technical operations involved in advanced exploration of most deposits, to say nothing of the still more involved problems of production. However, some deposits are too small to interest large companies but are rich enough to make mining by one man or a few men practical, and others are so rich that the discoverers prefer to work them themselves. These, however, are the exceptions, and this kind of mining should only be attempted by experienced persons or those who have studied the matter carefully. Such mining is sometimes done by those who have staked a property, and sometimes by lessees who undertake to mine material on a property where sufficient ore to interest a large company was not found, or where patches were left after a larger operation closed.



C. S. Lord 86083

Plate 84. A small mill in Northwest Territories.

Mining of this kind has been done in British Columbia for many years on small high-grade metal deposits mined fairly readily from adits. Another factor here is the presence of custom smelters in and near the province. The crude ore is generally shipped to a smelter after cobbing, i.e., breaking off richer parts of lumps, and sorting by hand; also, in some cases small mills that concentrate a ton or more of ore a day have been successful. Small-scale mining for metals has not been a feature of mining in the Canadian Shield, partly because most deposits mined successfully there tend to be large ones of moderate grade that require extensive operations, and partly because most of them have to be operated from shafts. An exception is the Cobalt district, where small high-grade silver veins were worked by independent miners and lessees, as well as by companies. A number of relatively small pegmatite deposits have been worked on a small scale in the Shield for feldspar, mica, and other minerals typical of pegmatites, generally by open-pit methods.

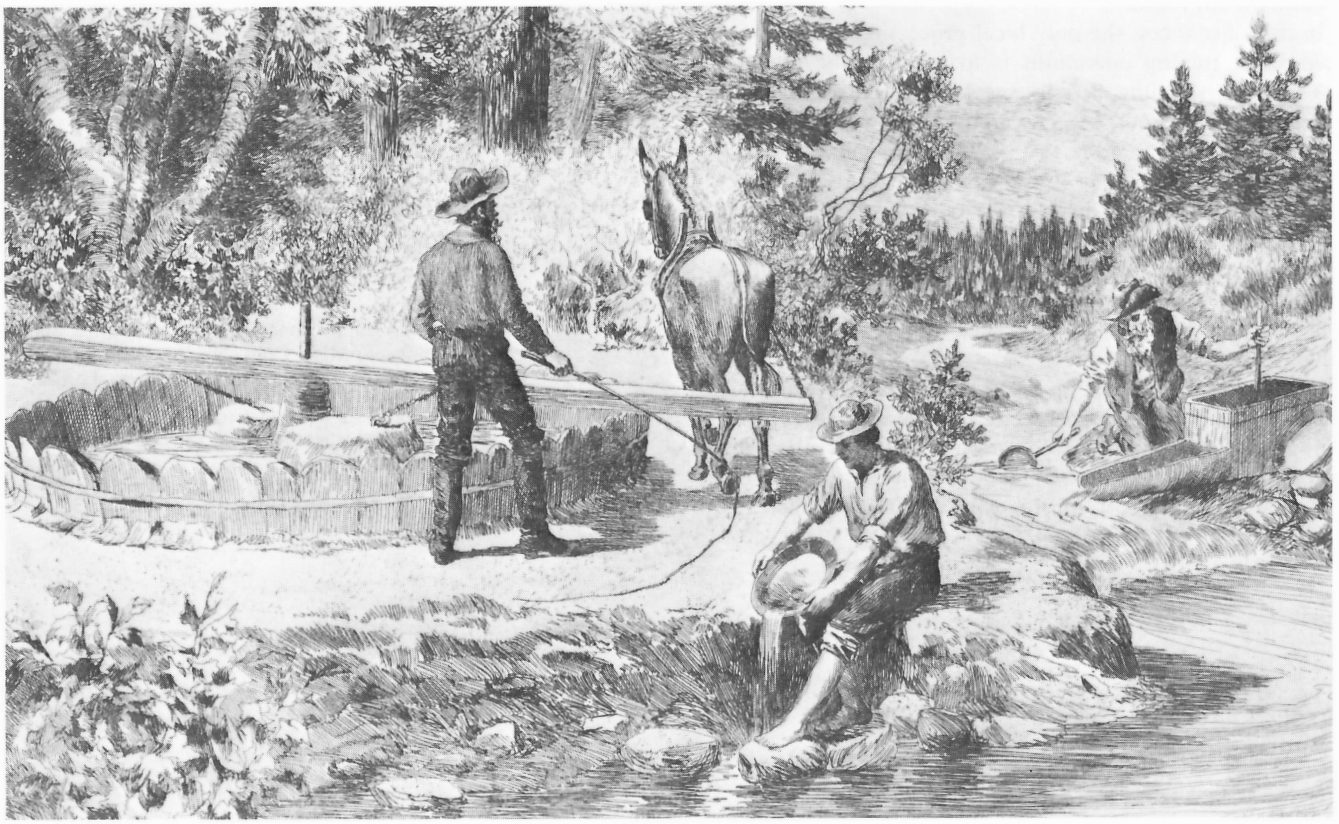
Small-scale mining, when practical, is a useful phase of the mineral industry because it permits production from deposits that would otherwise probably not be worked, because it permits gainful occupation, and because work of this kind may show that a deposit is larger and more important than it appeared to be. The disadvantages and the points about which caution should be exercised are: (1) even experienced miners may not have the necessary knowledge to decide whether a deposit can be profitably worked, or to understand the marketing of the product;



W. E. Cockfield 83417

Plate 85

A. A modern arrastra in British Columbia showing equipment for recovering mineral grains.



B. Drawing of an early arrastra, also showing rocking and panning of crushed ore (courtesy B.C. and Yukon Chamber of Mines).

(2) mining by inexperienced persons may be hazardous; (3) the profit from the sale of ore might be less than could be obtained as wages in some other occupation; and (4) it is possible to ruin a large deposit by mining the higher grade material only, as what is left may not be worth mining. Anyone contemplating work of this kind would be well advised to work for a mining company for a time to gain experience, to study the literature on the subject,

and to obtain advice from a provincial government engineer, if available, or a consulting engineer.

Mining Methods

The methods used in small-scale mining are about the same as those described in connection with the exploration of deposits. In open-pit work, blast holes may be drilled by hand steel, portable drills with built-in gasoline motors, or air drills used in connection with portable compressors. The methods are fairly similar to those used in blasting rock on construction projects. Underground mining is more complicated and requires more experience. The drilling may be done by hand steel, but this method is now rarely used underground except by those who cannot afford a portable compressor and air drill, or in places where it would be difficult to transport a compressor. Drills driven by attached gasoline engines are not used underground because of the fumes. Great care has to be used in storing and handling explosives, and in adhering to the elaborate regulations dealing with explosives and mine safety in general. Rock too weak to remain safely in place has to be supported by timbering. The rock broken by blasting is shovelled into a wheelbarrow or mine car and pushed to the surface, or into a bucket and hoisted.

Treatment Methods

In most instances, the only local processing done on ore from small mining operations is to sort out the material that is worth shipping. Strictly speaking, when the valuable material is picked out, the process is called 'selection', and when the reverse is done, by picking out and discarding unprofitable material, the process is called 'sorting'. Selection or sorting may be done in the mine or pit or at some other place on the property. At some mines the ore is dumped in a bin, from which a hopper discharges on to a 'picking table' or 'picking belt'. Large chunks may be cobbed with a hammer to allow separation of valuable and valueless pieces.

Milling and concentrating ore from a small operation, in a small plant at the property, is seldom done except on high-grade 'free-milling' gold ores, because of the very complex and expensive equipment usually required. Gold ores that contain most of the gold in grains sufficiently large to be free-milling, that is, to break free when ground, are sometimes successfully treated in small stamp or rotary mills driven by gasoline engines. The gold may be amalgamated with mercury or washed in sluice boxes or saved in other ways. In the early days arrastras (*see* Pl. 85) were sometimes used in British Columbia, particularly for grinding and amalgamating; an arrastra is an ancient Spanish and Mexican contrivance composed of a large tub-like enclosure in which the ore is ground by two large stones attached to a horizontal beam rotated by a mule or horse walking in a circle, or by a water-wheel.

Transportation

Ores that can be shipped profitably are transported to railways or docks by the best method suited to local conditions. If roads are available the ores may be hauled in trucks, jeeps, or wagons. Failing that, they may be carried on pack horses, or on a stone-boat hauled by a horse or tractor, or on a sleigh over a winter road. A method called 'rawhiding' was used considerably in the Cordilleran region in the early days, and may still be applicable in places. It consists of using a sack made of a raw beef hide, with the hair left on the outside for additional serviceability. The sack of ore is skidded down a mountain trail by a horse harnessed to the sack. Rich ores have occasionally warranted being transported by air.

Suggestions for Additional Reading

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1947: Geology for the layman; 2nd. ed., Northern Miner Press, Ltd.

Mining explained; Northern Miner Press Ltd. 1968

Practical mining: Textbooklet No. 3, Canadian Legion Educa-
1945: tional Services, Ottawa.

Stout, K.S.
1955: Practical guide for prospectors and small-mine operators in Montana; Misc. Cont. No. 13, *Montana Bur. Mines Geology*, Montana School of Mines.

Von Bernewitz, M.W.
1943: Handbook for prospectors and operators of small Mines; McGraw-Hill.
Contains information on prospecting, testing, and operating small mines, and on equipment for treating ores.



17 mining laws and other business matters

LAWS REGARDING PROSPECTING AND MINING

The control of prospecting, mineral rights, staking, mining, and related matters is vested in the various provincial governments and the administration of the Northwest Territories and Yukon Territory. There is no uniform law respecting these matters for Canada as a whole, because some of the laws and regulations took root when certain provinces were separate colonies, and because each province was later free to make its own laws to suit its particular needs and wishes. Now that better facilities for travel are available, a prospector may need to know the regulations for more than one province and to take out a licence for more than one. In addition to the provincial and territorial laws, there are also certain federal laws that affect prospecting and mining in a province. Examples are laws relating to atomic energy, explosives, income tax, and staking of claims and mining in national parks and Indian reserves.

Although the laws and regulations for the different jurisdictions follow more or less the same pattern, they differ in far too many details to be discussed fully here. A publication called "Digest of Canadian Mineral Laws", now in its sixth edition, summarizes the main features and is a useful reference, but it cannot cover all details or include changes since publication. Therefore a prospector must familiarize himself with the details for the province or territory in which he intends to prospect. Each province has a department of mines or equivalent; the Northwest Territories and Yukon Territory are administered by the federal department of Indian Affairs and Northern Development. Most provinces and territories are divided into Mining Districts or Divisions, for each of which there is a Mining Recording Office, and some districts are divided further into subdivisions for which there are suboffices. Information, copies of the full Acts and Regulations, and in some instances pamphlets explaining the principal regulations in non-legal language, can be obtained by calling at local recording offices, which are usually in county towns or towns where there is a Court House, or they may be obtained by writing to or calling at the headquarters of the department concerned. The names and addresses of these departments at the time of writing are listed in Appendix VII. The Department of Energy, Mines and Resources supplies only the summarized "Digest of Canadian Mineral Laws", which may be ordered from the Queen's Printer, Ottawa, at $4.00 a copy.

The following short discussions of the principal features of the laws regarding prospecting and mining are intended only to give a general idea of the subject, as an introduction for beginners in prospecting or newcomers to Canada. It is only a short account of the general pattern of the laws and regulations, and must be supplemented by obtaining and studying detailed, up-to-date information for the province or territory concerned. Legal details and changes that take place from time to time are obviously beyond the scope of this publication.

Historical Background

Some of the principles regarding mineral rights date from early mining in other parts of the world. It is worth while to consider these briefly, for in addition to being of historical interest, they help in understanding some present regulations and terminologies.

In ancient times, in the Old World, there was no question about the ownership of mineral rights. All belonged to emperors, kings, or feudal lords, for whom mines were worked by slaves and captives, often under the most appalling conditions. The Romans 'farmed out' the right to mine, particularly in conquered countries, to the owners of land. From very early times it was recognized that the monarch or the state must have the exclusive right to make coins; therefore gold and silver mines were in particular the property of kings and emperors. The Romans either permitted mining for base metals, for which a tax was charged, and withheld the right to mine gold and silver, or they permitted mining for gold and silver on payment of a special amount to the ruler; thus began the principle of paying a 'royalty', which persists to the present day.

In Roman times the owner of the soil was considered the owner of any underlying mineral rights that were granted, because then mines could be worked only to shallow depths beneath the surface. The true nature of deep lodes was unsuspected. During the Middle Ages, however, deeper mining was done, and in some places it became recognized that the discoverer of a lode should have title to it regardless of the ownership of the soil, provided that the landlord was compensated for surface damage. Thus the principle of a claim was established. It is said that in some parts of Europe the size of a claim was the distance the discoverer could throw his axe along the strike of the lode in both directions from the discovery. As serfdom was gradually abolished, miners became free men, and it is interesting to note that even today, in British Columbia, a prospecting permit is called a 'free miner's certificate'.

Thus basic principles that are common to all mining laws today are rooted in antiquity and have stood the test of time. These are: the right of the ruler or the state to dispose of mineral deposits; the right of the person or organization to whom mineral property is granted to maintain uninterrupted possession so long as the requirements are fulfilled;

and the right of the ruler or the state to collect a share of the product. These principles were brought to North America by the early colonists and have persisted, along with the conflicting theories of whether mineral rights belong to the landlord or are separate from land titles, and with the age-old concept that gold and silver rights should be treated separately from rights to other metals and minerals. In Canada it is now recognized that all mineral rights not already granted or withheld may be acquired by staking, regardless of the ownership of the surface rights, but old grants made under different terms are protected.

Another perplexing problem in mining rights, now happily a thing of the past in Canada, was the question of whether the owner of an inclined lode could follow it indefinitely, or only to a point vertically below the boundary of his claim or claims. The principle of unlimited ownership, so long as it could be proved that the lode, vein, fracture, etc. was continuous, called the principle of extralateral rights, was adopted in the early days of mining in the United States, and may have had its origin in somewhat similar rights claimed in parts of Europe long before. It was adopted in British Columbia as a result of an early influx of prospectors from the western states, but it caused so much confusion and litigation because of the difficulty of proving whether many lodes were in fact continuous or not that the law was repealed. In Canada all claim boundaries are now considered to extend vertically downward. It is important, therefore, for the staker of an inclined lode to consider whether it is necessary to stake an additional claim, or more, in order to cover the downward extension of the lode. This is called 'protecting the dip'.

Kinds of Mineral Rights

In general, there are separate laws and regulations governing the rights to lode deposits, placer deposits, coal, petroleum and natural gas, stone, gravel, sand, etc. The following topics deal with lode deposits, because they are of principal concern to prospectors.

Licences

The name of the licence to permit prospecting and staking of claims varies from province to province. It may be called a prospecting licence, miner's licence, miner's certificate, miner's permit, or free miner's certificate. The fee for an individual is usually $5 or $10, and the licence must be renewed annually at a similar charge. The licences are not transferable, but in some provinces the holder of a licence may stake a limited number of additional claims for another licence holder. A licence for one province or territory is not valid elsewhere.

Lands Open for Prospecting and Staking

Any person 18 years old or more who has obtained the necessary licence may prospect and stake on Crown lands, or on occupied lands if the mineral rights have been reserved to the Crown, except in special instances where lands have been withdrawn from staking. Citizens of other countries have the same rights as Canadians in this regard. In some provinces, incorporated companies may obtain licences, but the fee is usually much greater than for an individual; in other provinces, companies may obtain claims only by transfer from individual stakers.

In most parts of Canada, particularly in the less-settled regions, mineral rights are quite separate from surface rights. In such areas, unless staking is banned for a special reason, the prospector is only concerned with whether or not a particular piece of ground is already staked and whether such staking is in good standing. He can learn this by looking for claim lines and posts, or by consulting the local mining recorder. In many of the older parts of Canada, however, land titles may carry all the mineral rights, or all but the rights to gold and silver. A prospector is not usually permitted to enter upon or stake on land that carries mineral rights, unless by agreement with the owner. To verify whether a particular property carries mineral rights, it is necessary to consult the mining recorder or the land titles office.

If the surface and mining rights are separate, the owner of the land must be compensated for any damage done by the holder of mining rights. The latter is entitled to obtain such land as is needed for access and for working the deposit; if agreement with the owner cannot be reached, the matter may be settled by arbitration.

In the case of lands such as national and provincial parks, Indian reserves, townsites, lands occupied by buildings or required for highways or water-power projects, and certain summer resorts and railroad grants, staking may be either prohibited or permitted under special regulations. In such cases, the existing regulations should be studied.

Numbers and Sizes of Claims

The number of claims that a licence holder may stake in any one year varies greatly in different jurisdictions.

Lode claims are usually about 40 acres (1,320 feet to a side) or 51.65 acres (1,500 feet to a side). In areas that have been subdivided into townships and lots, claims must usually correspond to the appropriate lots. In unsurveyed territory the staker is supposed to arrange his claim lines as nearly as possible in north-south and east-west directions, and to make the sides approximately the correct length. There may be a penalty for oversize claims, or the authorities may reduce the size. If the manner of staking leaves gaps, which are called 'fractions' or 'fractional claims', these may be open for staking or there may be special provisions for their disposal.

Staking

Prospectors should study the local staking regulations carefully and endeavour to follow them in detail, because the haphazard staking often done not only causes much confusion and wasted time for others, but may cause the staker to lose title to his claims. In most provinces and territories, staking is done by placing a post at each corner of a claim, and by blazing and clearing brush from the side lines of the claims if they are in wooded country. Usually, posts must stand not less than 4 feet above ground

level, at least the upper foot being squared, with sides at least 4 inches wide (*see* Pl. 86). Posts may be set in place, or a tree stump properly squared will sometimes suffice. In regions where trees are lacking, a cairn of rocks may be used instead of a post, and pickets or mounds of earth or rocks may be used instead of blazes to mark the lines.

The northeast corner is usually the No. 1 post, and the other corners are called No. 2, No. 3, and No. 4 in clockwise order, the numbers being marked on the posts. On the No. 1 post is usually placed the name of the licence holder, the serial number of the licence, the date and hour of staking, and, if in surveyed territory, the numbers of the lot and concession or other legal description of the land covered by the claim. The name of the licencee, and other information in some provinces, is placed on posts 2, 3, and 4.

If claims are staked so as to adjoin one another, separate posts must usually be placed. Thus, if four claims adjoin, there would be four posts at their common corner, and these would be the No. 1 post of one claim, the No. 2 of another, the No. 3 of another, and the No. 4 of the fourth. If a corner of a claim is under water, 'witness posts' are placed where the claim lines intersect the shore; these are marked 'WP' together with a statement indicating the approximate direction and distance to the corner concerned. Claims that are entirely under water are staked by placing witness posts on the shore, in line with the claim boundaries. In some provinces, a post erected for one claim may also serve for an adjoining claim.

In several provinces, metal tags bearing claim numbers are supplied by the recorder. In some instances these are provided after recording and must be placed on the posts within a specified time. Another system is to supply tags for the number of claims a person is entitled to stake when the licence is issued; the staker then affixes the tags at the time of staking.

In western Canada claims are usually named as well as numbered. The usual practice now is to use short names consisting of two to four letters and, since there are not many of these, to use the same name for the claims comprising a group and to distinguish them by numbers, thus: Sol 1, Sol 2, Sol 3, etc. In earlier times, when men were



NFB 17180

Plate 86. Staking in the Northwest Territories (courtesy National Film Board).

not too hurried to write or carve long names on posts, the naming of claims often provided an outlet for romantic tendencies or wit.

A different system of staking is used in British Columbia and Yukon Territory, where important placer mining began in colonial times, earlier than in other parts of what is now Canada. The early placer regulations were based on Australian, American, and Mexican rules because the influx of miners came mainly from gold rushes in Australia and California that had taken place a few years earlier. When attention was turned to the possibilities of lodes, the method of staking was developed from the system for staking placer claims. The latter was to place two posts along the course of the stream, to mark the extent of the claim in that direction, and to allow a certain amount of ground on each side of the stream, without the necessity of placing posts at the corners. Lode claims were therefore staked by placing a 'discovery post' at the discovery and by placing No. 1 and No. 2 posts at appropriate distances from the discovery and along the strike of the lode. On these posts was placed a statement that the claim extended a certain distance on each side of the line joining the No. 1 and No. 2 posts. This system has an advantage in mountainous country, where it would be difficult for anyone but a surveyor to determine the corners of a square with sufficient accuracy for 'four-post staking', so the system has been continued in British Columbia and Yukon Territory, except that the requirement of a discovery post has been dropped. Claims may be laid out in any direction by placing No. 1 and No. 2 posts approximately 1,500 feet apart. The claim may lie 1,500 feet entirely to the right of the 'location' line joining the posts, or any part of 1,500 feet may lie to the right and the remainder to the left. If a claim so staked includes part of a claim previously staked and in good standing, only the unstaked portion is valid. Although the location line may be in any direction, where possible it should be north and south and the claim should be as nearly square as possible, as this lessens the likelihood of confusion, overlapping, and fractional claims. Because of the early distinction between placer deposits and quartz veins in western Canada, any kind of lode mining there is sometimes referred to as 'quartz mining'.

Recording

Claims must be recorded within a specified time after staking. This is usually 15 days for districts near a recording office, with an allowance for extra time for distance from the office. There may be a period after recording during which interested parties may appeal staking that they wish to dispute. In some places, if the recorder believes that there may be confliction as a result of several persons having staked at about the same time, or if searching of titles will require time, he may record a claim subject to verification. A recording fee is charged in most provinces.

Assessment Work

To retain title to a claim, a certain amount of work must be done each year on the claim or group of claims, unless there is provision for making a payment instead of doing work. Work of this kind is called 'assessment work' or 'representation'. The amount of work or payment varies considerably with different provinces or territories.

Obtaining Title

After the required work has been done, or payment has been made in lieu of work, and after the claim boundaries have been surveyed by an authorized surveyor if the claim is in an unsurveyed region, the claim may be patented or leased. Thereafter, it may usually be retained without further work, but a tax or rental based on acreage must be paid annually.

Taxes and Royalties

Apart from the small yearly acreage tax, governments collect revenues on production or profits from operating mines. The federal government collects revenue through income taxes, and from royalties on production in territories under its jurisdiction. The provincial governments charge taxes or royalties on production or profits. The provincial levies vary from province to province and with the scale of profits, and may be less for the first few years of production from a new mine. New mines have been exempt from income tax for the first three years.

Concessions

In certain regions, concessions or special licenses or permits giving the exclusive right to prospect or carry out geophysical surveys in a certain area (that may vary from a few to several hundred square miles) have been granted. They were sometimes confined to regions so remote that individual prospectors were unlikely to be active, or where the expenses involved in exploring the area would be great. Concessions have been disposed of by auction or on the payment of a substantial fee. The terms of some concessions limited the rights to a specific term of years, during which specified amounts of work must be done; at the expiration of the term, the holder could retain certain portions as mineral claims, the remainder being thrown open for general staking.

Parks

In parks under the jurisdiction of the federal government, no provision is made for the disposal of mining rights. In some provincial parks claims may be held under certain conditions.

Indian Reserves

In general, mineral rights for an Indian reserve are held for the benefit of the Indian Band. A licence to prospect may be issued by the Superintendent of the Indian Agency for the Reserve providing the Band Council has approved. However, a "surrender" of the mining rights by a referendum of the Band is required to authorize disposals for mining development. In most provinces Indian lands are governed by the Indian Mining Regulations which provide

for the granting of permits and leases with stipulated conditions for assessment work and the payment of rentals and royalties. On the other hand, in British Columbia Indian reserves authorized for development are taken up under provincial mining legislation after approval has been granted by the Band Council and the Superintendent. An applicant for mining rights will normally meet with the Band Council to present his proposals for prospecting and development.

Atomic Energy Regulations

The Atomic Energy Control Act gives the federal government certain control over prospecting and mining for uranium and thorium. The regulations made by virtue of the Act are designed to give all possible encouragement to prospecting and mining for uranium by the public, to exercise the necessary control over the destination of shipments and the publication and figures on production and ore reserves of producing mines, and to provide for the reporting of information on radioactive occurrences so that an inventory can be maintained and generalized information useful to prospectors and mine operators can be made available.

No special permit is required to prospect for uranium or thorium. A person simply obtains the appropriate provincial or territorial licence and stakes in the same way as for any other metal. The Atomic Energy Regulations are additional to the usual provincial and territorial regulations, those affecting prospecting and mining being as follows:

1. Anyone who finds or has reason to believe he has found an occurrence containing 0.05 per cent or more of uranium or thorium must promptly notify the Geological Survey of Canada, which acts as official agent of the Atomic Energy Control Board in matters related to the resources of radioactive materials. The notification should include all information available on the occurrence, and the location should be described accurately enough to permit the occurrence being found without a guide. The Geological Survey does not, however, undertake to examine discoveries at the request of the discoverers or owners. Notifications should be addressed to: The Director, Geological Survey of Canada. All information received is treated confidentially unless released by the sender or published elsewhere.

2. No further formalities in connection with preliminary exploration are required, but an exploration permit must be obtained from the *Secretary, Atomic Energy Control Board, P.O. Box 1046, Ottawa,* before undertaking advanced exploration, such as surface trenching to the extent of more than 300 man-days, any detailed geophysical or geological surveys such as would be accepted for assessment work, any diamond drilling or underground exploration, and any removal of *bulk* samples. Applications for permits should include:

(a) The full name and address of the applicant and, if the applicant is a corporation, the nature of its incorporation and the names and addresses of all its directors and officers;

(b) The name and address of the person who will be in charge of the work on the ground;

(c) A complete and accurate description by claim number, district, and province, or by lot and concession number, township, county or district, and province of all property intended to be covered by the order;

(d) A general description of the work contemplated;

(e) A consent by the holder of any existing exploration permit covering the property or any part thereof to the revocation of the existing permit.

An exploration permit stipulates that a detailed report on the results of exploration be sent annually during the first three months of each year to the Secretary of the Board. The report must include adequate plans, diamond-drill records, and assay data. Special reports do not usually need to be prepared, as most companies require that full reports be prepared for their own use, and if these are prepared for some other period than three months, arrangements can be made to have them accepted instead of quarterly reports. All information is treated confidentially.

An individual is permitted to publish any information he obtains on a discovery or property under exploration so long as the Geological Survey of Canada is also kept informed.

When the stage of production is approached, application must be made for a mining permit to replace the exploration permit. These permits are issued free of charge. If a property is abandoned or an option is dropped, the Atomic Energy Control Board should be asked to cancel or amend any permit that may have been issued.

METHODS OF FINANCING PROSPECTING

The typical old-time prospector was a rugged individualist who was willing to live and travel frugally for the sake of pursuing the kind of life he enjoyed and the chance of 'striking it rich'. He did not need great financial resources, and he generally obtained what he needed either by working for wages or trapping until he had saved enough, or by having someone provide a 'grubstake'. The latter implies the provision of groceries or the money to purchase them, usually on the understanding that the supplier will have a half interest in anything found; the use of 'stake' probably arises from the practice of staking one claim for the discoverer and one for the backer. Prospectors are still sometimes backed by a single grubstaker, but the expense of travel and equipment tends to make this prohibitive. The principal ways in which prospecting is now carried on are listed below.

Prospecting as an Avocation

An increasing number of persons take up prospecting as a hobby or minor occupation on week-ends and vacations. This can be an interesting and worthwhile pursuit for those who live away from the more settled parts of the country or who can spend vacations in favourable areas, provided

they study the subject as thoroughly as do those who follow any other avocation eagerly and intelligently.

Part-time Prospectors

There are still many prospectors who trap or work for wages, as miners or in other trades, during the winter and spend the summer prospecting.

Full-time Prospectors

A number of men make prospecting their full-time occupation. They usually spend a good part of the winter in the study of geological reports, maps, and air photographs with a view to planning work in the coming season. They may work independently or with a partner, and some make a good living by selling prospects; a few have made fortunes from exceptional discoveries.

Syndicates

Because of the cost of prospecting today, the old grubstaking system is now sometimes replaced by syndicates, several backers joining to pay the expenses of one prospector or more. An inexperienced prospector can seldom, if ever, obtain this sort of backing, but one of demonstrated ability and integrity can often interest a group of business or professional men; alternatively, such groups may take the initiative and be on the lookout for experienced men.

In an ordinary syndicate, the amount of money required for the venture is estimated and divided into 'units' of, say, $100 each; the members of the syndicate may then subscribe for an equal or unequal number of units and the prospector is apportioned the share agreed upon. If a worthwhile discovery is made, the claims might be sold and the proceeds apportioned on the basis of the number of units held by each participant, or a company might be formed, in which case each unit would be exchanged for a certain number of shares in the company. The prospector may be given a free hand, or a syndicate manager may be selected to handle business matters and to exercise some control over the prospector.

Ordinary syndicates have the disadvantage that the members may have to assume heavy responsibilities for debts, lawsuits, or misuse of funds. To rectify some of these problems, certain provinces have made provision for special partnerships and for the incorporation of small limited-liability companies to finance prospecting and early exploration of prospects.

Employment by Mining Companies

Companies that owned large producing mines commonly employed experienced prospectors in the hope that they would discover new deposits to increase the holdings or to take the place of the parent mines when they became exhausted. The degree of supervision varied. They were usually paid a monthly salary and supplied with all necessary equipment, groceries, and funds for travelling. In addition to salary, the company usually paid a specified bonus for a discovery that met certain specifications, or gave the prospector a certain share in the profits from a discovery that eventually proved productive. Often neither party favoured the latter arrangement, although it seems reasonable in some ways. The drawbacks were that the prospector would probably have to wait for several years before the property became productive, if it ever did so, and the company would have to continue paying a share of the profits to the prospector or his heirs throughout the life of the mine. Such employment of prospectors has changed with the times, but is still in effect to some degree.

Prospecting Programs

Organized prospecting schemes financed by companies are increasingly common. They may be conducted in what is believed to be a favourable area without acquiring ground beforehand, or on concessions or groups of claims. Most work of this kind now involves some combination of geological, geophysical, and geochemical surveys (*see* Chapters 10 to 13), but one or more conventional prospectors may be included and may work in teams each composed of two experienced prospectors or of one experienced man and one trainee; if the ground is being covered in great detail, a number of woodsmen or of university students without particular skill in prospecting may be employed to work under supervision. Payment may be entirely by salary, but there is usually some form of incentive bonus. The actual prospecting may be done by having the supervisor select a small area in which a team of prospectors will work for a time, after which the supervisor visits them and either instructs them how to continue in that area or moves them to another.

Government Grubstaking

Under certain circumstances, the governments of British Columbia and Saskatchewan assist residents of those provinces by providing funds or equipment for prospecting. Information is contained in literature supplied by the provincial department concerned. The Department of Indian Affairs and Northern Development organized in 1965 a grubstaking scheme for assisting, under certain circumstances, prospectors in the Yukon and Northwest Territories. Applications are made through local Mining Recorders, from whom information may be obtained.

Seeking Backing or Employment

Government departments receive numerous inquiries from prospectors regarding employment, but with the exception mentioned below government officials cannot assist in such matters. Companies in need of prospectors do, however, occasionally list their requirements with Canada Manpower Centres.

The best way for a prospector to obtain backing or employment if he does not know of suitable contacts, is probably to advertise in a mining paper or magazine or in a newspaper published in a mining district. He may also, by reading the mining press and consulting mining handbooks, ascertain what companies are actively engaged in prospecting and exploration.

Agreements

All agreements between prospecting partners, or between prospectors and grubstakers, syndicates, or companies should be in writing and should also be witnessed, with a view to avoiding disputes, disappointments, or misunderstandings. Agreements should preferably be drawn up by a lawyer, but if this is not possible the inexperienced prospector should consult a more experienced prospector or a business man in whom he has confidence. To avoid possible later complications all agreements should be drawn up as if they involve a future producing mine.

When granting an option it is advisable for the owner of the claim to try to have provision made for the party taking the option to supply him with full plans and other details in the event of the option being discontinued.

The following brief notes on prospecting agreements, based on instruction included in the prospecting courses given at Yellowknife, touch on some of the main features.

The area in which the prospecting or staking is to be done should be defined as nearly as possible, and the parties should agree on who is to do the actual staking. The handling and sharing of expenses should be specified. In regions where staking by proxy is permitted, it should be made clear whether the claims are to be left in the names of the persons for whom they are recorded or are to be transferred. Some agreement should be made as to the manner in which claims shall be sold or optioned; in some cases this may be left to the discretion of one party, whereas in others a majority of the associates must agree. In option agreements the claims involved, price, and terms of payment should be stated carefully. Where shares in a company are part of the consideration for the sale of a claim or property, the structure of the proposed company and the prospectors' share should be specified fully.

Disposing of Discoveries

Neither prospectors nor members of syndicates have, as a rule, the training, experience, or financial resources to undertake more than the preliminary exploration of a prospect. The mineral industry is very technical and highly specialized; in general, therefore, it is most practical and efficient for prospecting and preliminary exploration to be done by prospectors, and advanced exploration and mining by mining companies. Nowadays there are also companies that specialize in acquiring promising prospects, exploring them and, if the results are successful, selling them to mining companies.

Most companies are anxious to acquire promising prospects. Many prospectors, however, find it difficult to dispose of their claims or prospects, usually because their ideas of the value of the discovery differ widely from those of the company approached. Some prospectors pin their hopes on a showing that no company would consider, or they may attach too high a value to a prospect that a company would be willing to explore on different terms. These are matters for which there are no simple answers or remedies. It is true that some very successful mines have yielded little to the discoverer, but it is also true that sometimes prospectors have refused to come to terms and have died in poverty when they could have had a substantial payment or share in a discovery that was obviously important. The importance of discoveries is seldom apparent from the outset, however. In nearly all cases exploration has to be done by a slow process of elimination, as explained elsewhere, in which most prospects do not reach the producing stage. Those who finance such exploration risk their funds and the discoverer must usually be content with a settlement commensurate with the risk, or be prepared to wait until exploration has been completed. He will then receive nothing if it is a failure or may receive a large settlement if the results of exploration are successful.

Because of the risks involved, companies seldom buy a prospect outright. The usual procedure is to take an option by a legal agreement drawn up and signed by both parties in the presence of a witness, specifying that in consideration of a certain cash payment, generally small, the company undertakes to carry on exploration for a certain period of time, after which it may either abandon the property or buy it for a specified sum in cash or a specified number of shares, or both.

Companies interested in acquiring prospects commonly employ scouts who tour mining camps and prospecting fields, keeping in touch with prospectors and discoveries. Other companies wait for prospectors to approach them, and may have contacts with certain prospectors with whom they have established mutual respect and trust through previous dealings. Failing these methods of approach, a prospector may advertise claims or prospects in the mining press, or he can consult mining papers and periodicals for the names and addresses of companies that are active in exploration for a particular metal or mineral. The surest way to obtain a favourable hearing is by submitting samples that are representative of the deposit, rather than the selected ones that are generally obvious to an experienced mining man, and by being able to show a reasonably accurate sketch of the showings and sampling places. If the prospector is in doubt about the value of a discovery or the terms of an agreement, he should get advice from a consulting engineer or geologist, or a lawyer, or at least from a business man or other prospector in whom he has confidence. Government departments receive requests for advice but can seldom be of assistance because such matters are usually strictly business or legal questions, or lie within the sphere of consulting engineers or geologists.

Suggestions for Additional Reading

Lau, J.T.
1969: Pitfalls to beware of in mining agreements; *Northern Miner*, March 6, p. 23.

SERVICES OF GOVERNMENT DEPARTMENTS

Departments of the federal and of most provincial governments have different responsibilities connected with prospecting and mining, and provide various services of great importance to prospectors. The responsibilities of the different organizations are kept as distinct as possible, so

that the work can be done with maximum efficiency and minimum overlapping, but more than one organization may undertake certain services such as geological mapping, because of the great amount of work needed. The activities of different departments are outlined here to assist prospectors to learn the appropriate agencies to contact for publications or regulations.

The federal government has two departments of particular concern to prospectors, one being the Department of Indian Affairs and Northern Development, and the other the Department of Energy, Mines and Resources. The Geological Survey of Canada, a branch of the latter Department, is most closely connected with prospecting, so its activities are outlined in more detail later. The Mines Branch is mainly concerned with research on methods of treating ores, fuels, etc., and on new or improved uses for metals, alloys, minerals and mineral products; therefore its activities are chiefly connected with phases of the mineral industry that follow the preliminary work of prospecting; samples from sizable deposits of industrial minerals or rocks may be submitted for advice. The Mineral Resources Branch publishes information on resources, markets, prices, and uses of minerals produced in Canada. The Surveys and Mapping Branch publishes topographical maps and administers the National Air Photographic Library. The Mineral Processing Division will advise on samples from industrial deposits. The Department of Energy, Mines and Resources does not do assaying for the public.

The Northern Economic Development Branch of the Department of Indian Affairs and Northern Development administers mining laws and regulations for the Yukon and Northwest Territories. It is responsible for information on staking and for the recording of claims, assessment work, and mine safety in this region. Its main office is at Ottawa, and it has offices at Whitehorse and Yellowknife.

When writing for maps or reports, sending specimens, etc., it is important to keep in mind the distinctive services of government agencies, which may be in widely separated locations. Delays and, possibly, loss of letters or samples may be caused by improper addressing and by requesting the publications or services of various agencies in a single letter. The functions of the agencies, as outlined here, and the addresses listed in an appendix should be carefully noted.

Geological Survey of Canada

The Geological Survey of Canada was formed in 1842 and is the oldest scientific organization in the country. Its primary purpose is to map and study the geology of the country and to provide maps and reports that help prospectors and companies in the selection of their fields of operation and that help to guide their work. In this way the Geological Survey has contributed indirectly to the discovery and development of most Canadian mines. In addition to geological mapping divisions, it has special units devoted to the study of mineral deposits, petroleum and coal, mineralogy, geophysics, Pleistocene geology, engineering geology and the study of fossils.

In a little more than a century, the Geological Survey has grown from a staff of two or three men to an organization that now places from 70 to 90 parties in the field each year and also has specialized laboratory and other staffs. It has published roughly five thousand different maps and reports, yet there are many parts of Canada that have not been investigated even in reconnaissance fashion; vast areas are in need of more detailed work; many areas that were covered in considerable detail now require revision in the light of new knowledge, new exposures, and new needs; and many problems await special investigation.

The Geological Survey is not itself a prospecting organization, although its geologists have made important discoveries from time to time while mapping, and it has undertaken special prospecting programs in times of emergency.

Catalogues of publications are available and individuals or companies may also be placed on a notice list for cards announcing new publications. A charge to help cover the cost of printing is made for most publications, and requests by mail should be accompanied by a money order payable to the Receiver General of Canada. If the exact charge is not known and an excess is sent with the order, the balance will be returned. Publications should be ordered from the Geological Survey of Canada or the Queen's Printer, Ottawa, or publications covering their respective regions may be obtained from branch offices of the Geological Survey of Canada at Vancouver, and Calgary, and the Resident Geologists at Whitehorse and Yellowknife. Publications, including many out of print, can be studied at the head and branch offices of the Geological Survey of Canada, and libraries can arrange to borrow out-of-print publications of the Geological Survey from its library.

Letters sent to the head office of the Geological Survey should usually be addressed to the Director rather than to individual officers, because the latter may no longer be on the staff or may be in the field.

The Geological Survey also sells sets of rocks and minerals to assist students and prospectors. A price list is available and it and the specimens should be ordered from the Director.

Minerals are identified free of charge. Specimens should be addressed to "Director, Geological Survey of Canada, 601 Booth Street, Ottawa", and marked "for mineral identification". Information on the exact locality concerned, and other particulars, is appreciated.

Officers of the Geological Survey are pleased to assist prospectors individually when possible, but there are limitations on what can be done, because they do not attempt to duplicate the services of consulting geologists and engineers. Giving information in advance of publication is restricted to that information that would not confer an unfair advantage and that pertains only to the mining property owned by the applicant. Where a property is owned by a company it is possible to discuss it only with an official of the company. The Geological Survey does not examine a discovery at the request of the discoverer or owner, although it examines many discoveries and properties in the course of its work, and at such times is pleased

to give what advice it can. Its officers can devote only a fraction of their time to inquiries by callers and by correspondence because such inquiries delay the preparation of maps and reports. Those seeking information should first obtain the publications available on the matter in question as they usually contain all the information the Geological Survey possesses or is able to impart.

Services of Provincial Governments

Most provinces have a department of mines or a mines branch in another department. These departments are responsible for all matters connected with staking, assessment work, mine safety, etc., and many of them also provide services that assist prospectors greatly. These services vary from one province to another and from time to time and are more extensive in those provinces where mining is a major industry. In several instances they consist of pamphlets giving general advice on prospecting in the province, annual reports describing mining properties, geological maps and reports on certain areas, and free identifications, spectrographic analyses, or assays on a limited number of samples. In some provinces a certain number of coupons are issued with a prospecting permit, entitling the prospector to one assay per coupon. Mining engineers or geologists may also examine discoveries and advise prospectors, but no department attempts to meet all requests for such examinations. For particulars, mining recorders or other officials of the department concerned may be consulted, or a letter may be sent to the head office of the department. The names of the provincial departments and the addresses of their head offices are listed in Appendix V.

APPENDICES

I. Table of elements

II. Periodic table of the elements

III. Abundance of elements in average igneous rocks

IV. Introductory mineral table

V. Field classifications of common rocks

VI. Some equipment and tests for identifying minerals

VII. Addresses

APPENDIX I

Table of Elements

The elements, as mentioned in Chapter 3, are the basic substances of which matter is composed. Under normal conditions, most elements are solid. Eleven are gases, and two, bromine and mercury, are liquids. The elements are sometimes roughly classified under the heads of metals, semi-metals (or metalloids), non-metals, and gases. However, this classification is merely a matter of convenience, and not a scientific definition. For the purpose of this table, substances having what is known as 'metallic lustre' are classified as metals, and those without as non-metals. Those elements which are gaseous at normal temperature and pressure are classified as gases, e.g. oxygen, nitrogen; two such elements, however, chlorine and fluorine, are rarely, if ever, found as gases, but occur in combination with other elements.

Elements marked with an asterisk belong to the rare earth groups, to which scandium and yttrium are closely related.

Table of Elements

Atomic Number	Name	Symbol	Nature	Atomic Weight
89	Actinium	Ac	metal (?)	227
13	Aluminum	Al	metal	27.0
95	Americium	Am	metal (?)	243
51	Antimony	Sb	semi-metal	121.8
18	Argon	A	gas	39.9
33	Arsenic	As	semi-metal	74.9
85	Astatine	At	non-metal	210
56	Barium	Ba	metal	137.4
97	Berkelium	Bk	metal	245
4	Beryllium	Be	metal	9.0
83	Bismuth	Bi	metal	209
5	Boron	B	non-metal	10.8
35	Bromine	Br	non-metal	79.9
48	Cadmium	Cd	metal	112.4
55	Caesium	Cs	metal	132.9
20	Calcium	Ca	metal	40.1
98	Californium	Cf	metal	248
6	Carbon	C	non-metal	12.0
58	Cerium*	Ce	metal	140.1
17	Chlorine	Cl	gas	35.5
24	Chromium	Cr	metal	52.0
27	Cobalt	Co	metal	58.9
	Columbium (*see* Niobium)			
29	Copper	Cu	metal	63.5
96	Curium	Cm	metal (?)	245
66	Dysprosium*	Dy	metal	162.5
99	Einsteinium	Es		254.0
68	Erbium*	Er	metal	167.2
63	Europium*	Eu	metal	152
100	Fermium	Fm		253.0
9	Fluorine	F	gas	19
87	Francium	Fr	metal	223
64	Gadolinium*	Gd	metal	156.9
31	Gallium	Ga	metal	69.7
32	Germanium	Ge	metal	72.6
79	Gold	Au	metal	197.0
72	Hafnium	Hf	metal	178.6
2	Helium	He	gas	4.0
67	Holmium*	Ho	metal	164.9
1	Hydrogen	H	gas	1.0
49	Indium	In	metal	114.8
53	Iodine	I	non-metal	126.9
77	Iridium	Ir	metal	192.2
26	Iron	Fe	metal	55.9
36	Krypton	Kr	gas	83.8
57	Lanthanum*	La	metal	138.9
103	Lawrencium	Lw		257.0
82	Lead	Pb	metal	207.2
3	Lithium	Li	metal	6.9
71	Lutetium*	Lu	metal	175.0
12	Magnesium	Mg	metal	24.3
25	Manganese	Mn	metal	54.9
101	Mendelevium	Md		256.0
80	Mercury	Hg	metal (liquid)	200.6
42	Molybdenum	Mo	metal	96.0
60	Neodymium*	Nd	metal	144.3
10	Neon	Ne	gas	20.2
93	Neptunium	Np	metal	237
28	Nickel	Ni	metal	58.7
41	Niobium (formerly columbium)	Nb	metal	92.9
7	Nitrogen	N	gas	14.0
102	Nobelium	No		254.0
76	Osmium	Os	metal	190.2
8	Oxygen	O	gas	16
46	Palladium	Pd	metal	106.7
15	Phosphorus	P	non-metal	31.0
78	Platinum	Pt	metal	195.2
94	Plutonium	Pu	metal	242
84	Polonium	Po	metal	210
19	Potassium	K	metal	39.1
59	Praseodymium*	Pr	metal	140.9
61	Promethium*	Pm	metal	145
91	Protoactinium	Pa	metal (?)	231
88	Radium	Ra	metal	226.1
86	Radon	Rn	gas	222
75	Rhenium	Re	metal	186.3
45	Rhodium	Rh	metal	102.9
37	Rubidium	Rb	metal	85.5
44	Ruthenium	Ru	metal	101.1
62	Samarium*	Sm	metal	150.4
21	Scandium	Sc	metal	45.0
34	Selenium	Se	non-metal	79.0
14	Silicon	Si	non-metal	28.1
47	Silver	Ag	metal	107.9
11	Sodium	Na	metal	23.0
38	Strontium	Sr	metal	87.6
16	Sulphur	S	non-metal	32.1
73	Tantalum	Ta	metal	181.0
43	Technetium	Tc	metal	99
52	Tellurium	Te	non-metal	127.6
65	Terbium*	Tb	metal	158.9
81	Thallium	Tl	metal	204.4
90	Thorium	Th	metal	232.1
69	Thulium*	Tm	(rare-earth metal?)	168.9
50	Tin	Sn	metal	118.7
22	Titanium	Ti	metal	47.9
74	Tungsten	W	metal	183.9
92	Uranium	U	metal	238.1
23	Vanadium	V	metal	51.0
	Wolfram (*see* Tungsten)			
54	Xenon	Xe	gas	131.3
70	Ytterbium*	Yb	metal	173.0
39	Yttrium	Y	metal	88.9
30	Zinc	Zn	metal	65.4
40	Zirconium	Zr	metal	91.2

APPENDIX II

Main Features of the Periodic Table

Early versions of the Periodic Law stated that the properties of elements are periodic functions of their atomic weights. This conclusion was reached because, if the elements are arranged in series according to increasing atomic weights (*see* Appendix I) it is found that some of the chemical properties are repeated, commonly in 'periods' of eight elements. This led to the construction of 'periodic tables' in which the horizontal rows were called 'periods' and the vertical columns were called 'groups'. Although some inconsistencies were unexplained, the concept was of great use and led to the discovery of several new elements.

Advances in knowledge of the structures of atoms resulted in a restatement of the Periodic Law that removed the previous inconsistencies, by showing that the properties of elements are periodic functions of their atomic numbers, rather than of their atomic weights. Atoms consist of a nucleus carrying positive electrical charges, surrounded by a cloud of orbiting electrons carrying an equal number of negative charges. Some of the main chemical properties, including valence, are determined by the number of electrons in the outer orbits or 'shells'. It was found that, if 'atomic numbers' are assigned according to the X-ray properties of elements, these numbers correspond to the number of net positive charges on the nuclei and also to the numbers of negatively charged electrons. Series based on these numbers correspond mainly to those based on increasing atomic weights, but a few pairs, such as cobalt and nickel, are reversed. The horizontal series or periods can be arranged in different ways, a common one being that of the accompanying table (Periodic Table). It shows only the bare essentials of atomic numbers and chemical symbols, which can be compared with the names in Appendix I. Two special series at the bottom of the table are provided for the 'lanthanide contraction' which comprises the fourteen rare earth elements between 57 and 72, and for the 'actinide contraction' following 89. The latter includes many of the radioactive elements which, excepting potassium and rubidium, begin with polonium (84). Technetium, promethium, and the elements following uranium have been made only in the laboratory and are not known to occur in nature.

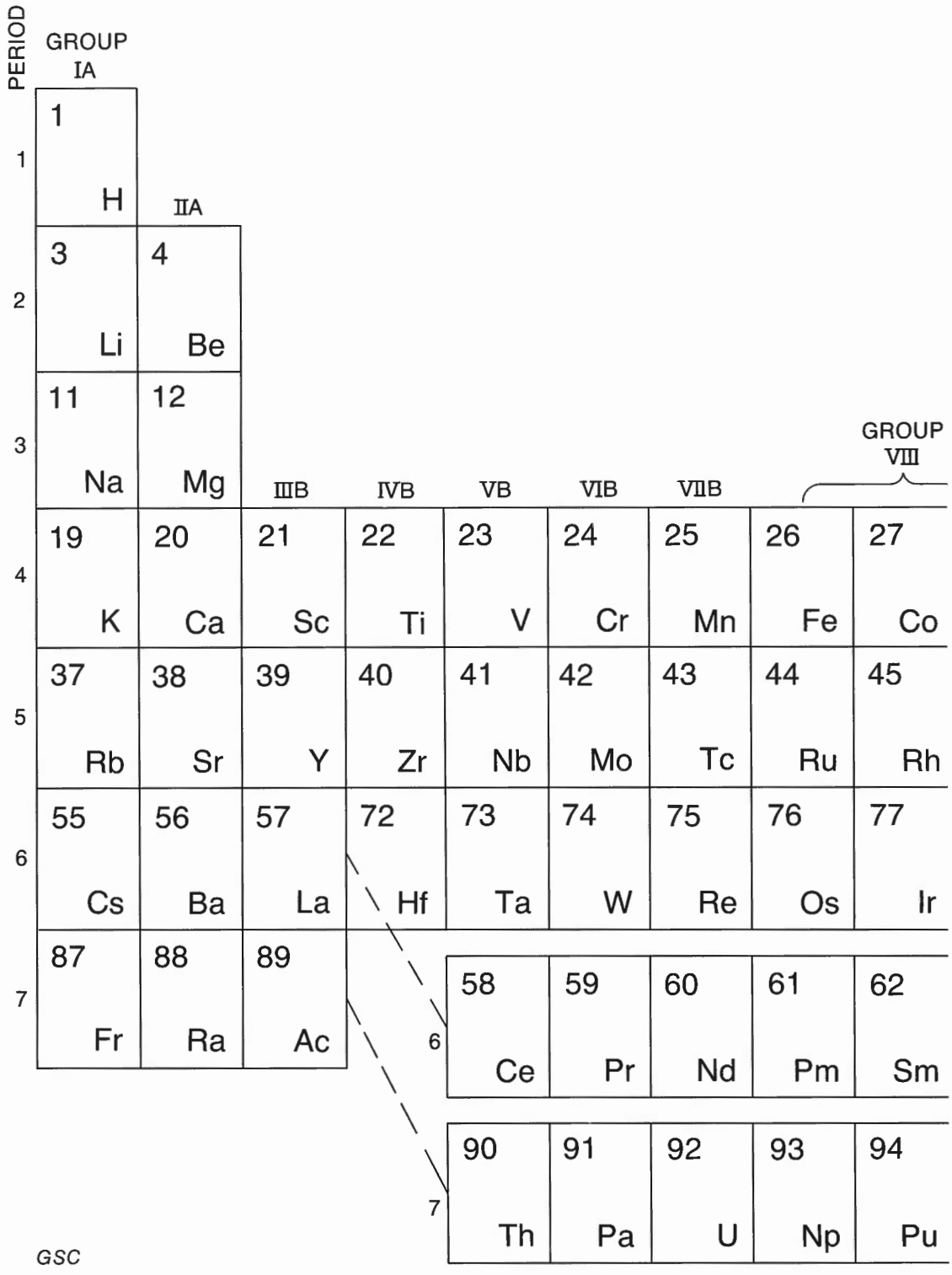
Only a few of the relationships exhibited by the table can be mentioned here. The first group contains the alkali elements. The last comprises the inert gases, which cannot react with other elements because their outer shells of electrons are complete. Cobalt and nickel, nickel and copper, copper and zinc show horizontal affinities. Copper, silver, and gold, show vertical affinities, as do zinc and cadmium. The platinum group (44, 45, 46, 76, 77, 78) show both horizontal and vertical grouping. The gases are grouped roughly triangularly in the upper and right-hand part of the table. The heavy zig-zag line separates metals from non-metals. Elements that tend to form silicates are at the left side of the table. Elements with affinity for sulphur and thus tending to form sulphides lie mainly in the right upper centre of the table.

APPENDIX III

Abundance of Elements in Average Igneous Rocks

Element	Content (ppm)	Content (per cent)
Aluminum	81,000	8.1
Antimony	0.3	0.000,03
Arsenic	2	0.000,2
Barium	640	0.064
Beryllium	4.2	0.000,42
Bismuth	0.1	0.000,01
Boron	13	0.001,3
Bromine	1.8	0.000,18
Cadmium	0.13	0.000,013
Calcium	33,000	3.3
Carbon	230	0.023,0
Cerium	40	0.004
Cesium	10	0.001
Chlorine	230	0.023,0
Chromium	117	0.011,7
Cobalt	18	0.001,8
Copper	70	0.007
Fluorine	660	0.066
Gallium	26	0.002,6
Germanium	2	0.000,2
Gold	0.001	0.000,000,1
Hafnium	3	0.006,3
Indium	0.1	0.000,01
Iodine	0.4	0.000,04
Iridium	0.001	0.000,000,1
Iron	46,500	4.65
Lead	16	0.001,6
Lithium	50	0.005
Magnesium	17,000	1.7
Manganese	1,000	0.1
Mercury	0.06	0.000,006
Molybdenum	1.7	0.000,17
Nickel	100	0.01
Niobium	20	0.002
Osmium	0.0001	0.000,000,01
Oxygen	473,000	47.3
Palladium	0.02	0.000,002
Phosphorus	900	0.09
Platinum	0.005	0.000,000,5
Potassium	25,000	2.5
Rhenium	0.001	0.000,000,1
Rhodium	0.001	0.000,000,1
Rubidium	280	0.028
Ruthenium	0.0001	0.000,000,01
Scandium	13	0.001,3
Selenium	0.01	0.000,001
Silicon	291,000	29.1
Silver	0.2	0.000,02
Sodium	25,000	2.5
Strontium	350	0.035
Sulphur	900	0.09
Tantalum	2.7	0.000,27
Tellurium	0.001	0.000,000,1
Thallium	1.7	0.000,17
Thorium	13	0.001,3
Tin	32	0.003,2
Titanium	4,400	0.44
Tungsten	2	0.000,2
Uranium	2.6	0.000,26
Vanadium	90	0.009
Zinc	80	0.008
Zirconium	170	0.017

Modified from Hawkes and Webb: *Geochemistry in Mineral Exploration*; Harper and Row, Publishers, New York, 1962, p. 22.



Appendix II. A periodic table of th
atomic numbers.

								VIII
								2 He
			IIIA	IVA	VA	VIA	VIIA	
			5 B	6 C	7 N	8 O	9 F	10 Ne
			13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
	IB	IIB						
28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lw

e elements arranged in the order of

APPENDIX IV

Introductory Mineral Table[1]

(Compiled by H. R. Steacy)

Note: This table is available as a booklet from the Geological Survey of Canada or Queen's Printer at 50 cents each.

A. Minerals with Metallic or Sub-metallic Lustre[2]

Name and Composition	Hardness[3]	Characteristics	Remarks
1. Colour is white to light grey — streak[4] is white			
Silver Ag	2·5–3	Wiry forms, leaves, scales, and plates. Malleable. Very heavy. Colour and streak silver-white, but tarnishes grey to black.	Often alloyed with gold. Almost always tarnished except on a very fresh surface.
2. Colour is white to light grey — streak is greyish black to black			
Cobaltite CoAsS	5·5	Commonly as small crystals with striated faces; sometimes massive. Colour, silver-white, often with reddish tinge. Streak, greyish black.	A source of cobalt; alters to pink erythrite.
Arsenopyrite FeAsS	5·5–6	Massive; disseminated crystals, conspicuously striated. Colour, silver-white to steel-grey. Streak, greyish black. Garlic odour on breaking.	Source of white arsenic. Often contains cobalt, and silver; sometimes gold.
Skutterudite (CoNi) As_3	6	Usually massive. Colour between tin-white and silver-grey; sometimes tarnished grey. Streak, greyish black.	Skutterudite is the name given to a series of cobalt-nickel arsenides of similar crystal structure. The minerals smaltite and chloanthite are included in the series. Colour resembles aluminum paint.
3. Colour is lead-grey to black — streak is white, grey, light brown, or red			
Molybdenite MoS_2	1–1·5	Commonly in flakes or foliated masses[5]. Greasy feel. Sectile. Laminae flexible. Colour, lead-grey. Streak, greenish grey on porcelain, bluish grey on paper. Yields sulphurous fumes on heating.	Important source of molybdenum. Found in pegmatites; in veins, associated with scheelite, wolframite, and fluorite; and as an accessory mineral in granites. Differs from graphite in colour and streak, and in effect on heating.
Silver Ag	2·5–3	Wiry forms, leaves, scales, and plates. Malleable. Very heavy. Colour and streak silver-white, but tarnishes grey to black.	Often alloyed with gold. Almost always tarnished except on a very fresh surface.

[1] The minerals listed are those recommended for first study. Because of variable characteristics, a mineral may appear in more than one place in the table.

Many minerals can be identified by their physical properties, and as these properties vary for each mineral they provide a useful means of classification. This table is an introductory classification based on lustre, colour and hardness. The listed minerals are first divided into two main categories: (A) those having a metallic or sub-metallic lustre, and (B) those having a non-metallic lustre. Minerals in each main category are then subdivided according to colour, and finally within each colour group they are arranged in order of increasing hardness. Metallic minerals are further subdivided on the basis of their streak. Close attention should be paid to the various footnotes. For more complete descriptions, standard textbooks on mineralogy should be consulted.

[2] Lustre of a mineral is the general appearance of a freshly broken mineral surface, and may be metallic, when the surface resembles metallic substances, or non-metallic. A lustre intermediate between the two is said to be sub-metallic. Non-metallic lustre is further defined in the table by such self-explanatory terms as brilliant, dull, glassy, greasy, pearly, resinous, splendent, pitchy, and waxy.

[3] Hardness is one of the most useful properties in identifying minerals. The numbers listed in this column indicate the relative hardness of the minerals, as determined by comparison with a standard scale. This is known as Mohs' Scale of Hardness and consists of the following ten minerals of relative increasing hardness: 1–Talc; 2–Gypsum; 3–Calcite; 4–Fluorite; 5–Apatite; 6–Feldspar; 7–Quartz; 8–Topaz, 9–Corundum; 10–Diamond. The hardness is best determined by scratching the mineral on a smooth surface. The finger nail has a hardness value of about 2.5. The blade of an ordinary pocket-knife has a value of 5.5 to 6.

[4] The streak is the colour of the finely powdered mineral. It may be determined by powdering a fragment of the mineral, by filing it, or by rubbing it across a piece of unglazed white porcelain. The streak is especially helpful in identifying minerals of metallic or sub-metallic lustre. These minerals have therefore been subclassified according to their streak.

[5] Some minerals occur typically as well-formed crystals, but most occur in masses showing no external crystalline form. The structure of such masses may be cleavable, granular, lamellar, columnar, fibrous, bladed, foliated, scaly, botryoidal, or compact. Cleavable masses break along smooth, flat surfaces; granular masses are composed of individual grains, either coarse or fine; lamellar masses are made up of thin layers; columnar masses are made up of slender columns; fibrous masses are made up of fibres, which may be coarse or fine and which may or may not be separable; bladed masses are composed of thin blades; foliated masses are made up of thin plates, or leaves, which are easily separable; scaly masses consist of thin, easily separable scales; botryoidal masses have rounded surfaces, resembling a bunch of grapes; and compact masses are dense granular masses which are very resistant to fracturing or breaking.

Introductory Mineral Table (*cont.*)

A. Minerals with Metallic or Sub-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
3. Colour is lead-grey to black — streak is white, grey, light brown, or red (cont.)			
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, black, brown, or yellow. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Hematite Fe_2O_3	5–6	Compact, granular, botryoidal, and earthy masses. Colour, steel-grey to reddish brown. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite*[1] has a micaceous structure with a splendent lustre.
Cassiterite SnO_2	6–7	Massive and as crystals (ordinary); botryoidal, with fibrous structure (wood tin); rolled grains (stream tin). Heavy. Colour usually black or brown. Streak, greyish to brownish.	Most important source of tin. Commonly occurs in veins closely associated with granitic rocks or pegmatites. Often in placer deposits.
4. Colour is lead-grey to black — streak is dark brown or black			
Graphite C	1–2	Commonly in flakes or foliated masses. Greasy feel. Sectile. Laminae flexible. Colour, steel-grey to iron-black. Streak, shining black.	Found mainly in metamorphic rocks; common in crystalline limestone. Colour and streak aid in distinguishing it from molybdenite.
Stibnite Sb_2S_3	2	Columnar and bladed masses; aggregates of needle-like crystals, often striated and bent. Perfect cleavage. Colour and streak, lead-grey. Thin edge fuses in candle flame.	Most important source of antimony. Harder than graphite. Lighter than galena.
Pyrolusite MnO_2	2–2·5	Usually as fibrous, granular, or powdery masses; also as coatings. Colour, steel-grey to iron-black. Streak, black to bluish black. Soils the fingers.	A source of manganese. Secondary in origin.
Galena PbS	2·5	Massive, with cubic cleavage; sometimes as crystals, usually cubic. Heavy. Colour and streak, pure lead-grey.	Most important source of lead. Frequently contains silver.
Chalcocite Cu_2S	2·5–3	Massive; also as crystals, deeply striated and frequently twinned. Heavy. Rather sectile. Colour and streak, blackish lead-grey; often tarnished blue or green.	Important source of copper. Usually associated with other copper minerals.
Tetrahedrite $(CuFe)_{12}Sb_4S_{13}$	3–4	Massive; also as tetrahedral crystals. Brilliant lustre. Colour, flint-grey to iron-black. Streak, brown to black.	A source of copper. Often contains silver.
Wolframite (FeMn) WO_4	5–5·5	Granular or lamellar masses; also as crystals, usually striated, and as rolled grains. Perfect cleavage. Heavy. Sometimes weakly magnetic. Colour, dark grey to brownish black. Streak, dark brownish to black. Fuses easily.	A source of tungsten. Occurs in quartz veins, pegmatites, and granites. Commonly associated with cassiterite and scheelite. Often found in placer deposits.
Chromite $FeCr_2O_4$	5·5	Granular to compact masses. Sometimes feebly magnetic. Colour, iron-black to brownish black. Streak, brown.	A source of chromium. Occurs commonly in serpentinized basic rocks; also found in placers. Distinguished from magnetite by streak and feeble magnetic property.
Ilmenite $FeTiO_3$	5–6	Granular and compact masses. Slightly magnetic. Colour, iron-black. Streak, brownish to black.	A source of titanium. Often intergrown with magnetite. Commonly present in black sands.
Uraninite UO_2	5–6	Typically as well-developed cubic and octahedral crystals. Heavy. Strongly radioactive. Colour, steel-black to black. Streak, black.	Occurs mainly in granite and syenite pegmatites. Usually contains several per cent thorium and rare earths.
Uraninite, variety *pitchblende* UO_2	5–6	Massive, sometimes in rounded or botryoidal forms; also finely disseminated. Heavy. Pitchy lustre. Colour, dark steely to pitch-black. Streak, black. Strongly radioactive.	Occurs in vein-type deposits. Often associated with hematite. Practically free of thorium and rare earths.

[1] Names in italics are varieties of the species described, e.g., *specularite* is a variety of hematite.

Introductory Mineral Table (*cont.*)

A. Minerals with Metallic or Sub-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
4. Colour is lead-grey to black — streak is dark brown or black (cont.)			
Magnetite Fe_3O_4	5·5–6·5	Usually as granular masses sometimes as octahedral crystals. Octahedral parting. Strongly magnetic. Colour and streak, black.	Important source of iron. Alters to limonite and hematite. Widespread occurrence. Very common in black sands.
Columbite–tantalite $(FeMn)(NbTa)_2O_6$	6	Platy or rectangular crystals, often in radial or parallel aggregates; disseminated grains. Quite heavy. Colour and streak, brownish black to iron-black. Frequently iridescent.	A source of columbium and tantalum. Commonly occurs in pegmatites.
5. Colour is yellow, brass, or bronze — streak is yellow or black			
Gold Au	2·5–3	Commonly in flakes, scales, and wires. Hackly fracture. Malleable. Very heavy. Colour and streak, golden yellow.	Generally alloyed with silver. Frequently found in quartz veins; also in placer deposits as flakes or nuggets, when it may be easily panned.
Bornite Cu_5FeS_4	3	Massive. Colour, bronze-red on fresh surface; tarnishes readily to purple. Streak, greyish black.	A source of copper. Sometimes called 'peacock ore' or 'purple copper ore'.
Chalcopyrite $CuFeS_2$	3·5–4	Massive. Colour, brass-yellow; often tarnished and iridescent. Streak, greenish black.	Most important source of copper. Sometimes contains gold and silver.
Pyrrhotite Fe_7S_8	3·5–4	Massive, usually granular. Weakly magnetic. Colour, bronze-yellow to copper-red; tarnishes quickly. Streak, greyish black.	May contain nickel, owing to the presence of pentlandite. Magnetic property distinguishes it from chalcopyrite and pyrite.
Pentlandite $(FeNi)S$	3·5–4	Massive and disseminated. Colour, light bronze-yellow. Streak, light bronze-brown.	A source of nickel. Almost always found associated with pyrrhotite.
Pyrite FeS_2	6–6·5	Massive, frequently fine granular; cubic crystals common, often striated. Colour, pale brass-yellow. Streak, greenish black or brownish black.	Most common sulphide mineral. Alters to limonite. May contain gold. Hardness distinguishes it from chalcopyrite, pyrrhotite, and gold.
6. Colour is red or brown — streak is red or brown			
Copper Cu	2·5–3	Masses; scales; distorted crystals. Hackly fracture. Malleable. Heavy. Colour and streak, copper-red.	Often stained with green and blue secondary copper minerals.
Cinnabar HgS	2–2·5	Earthy coatings; crystalline crusts; and massive. Heavy. Colour, bright red. Streak, scarlet. On being heated, it produces sulphurous fumes and minute globules of mercury.	Principal source of mercury. Resembles some varieties of hematite, but distinguished by heating test.
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, brown, yellow, or black. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Hematite Fe_2O_3	5·5–6·5	Compact, granular, botryoidal, and earthy masses. Colour, reddish brown to steel-grey. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite* has a micaceous structure with a splendent lustre.
Cassiterite SnO_2	6–7	Massive and as crystals (ordinary); botryoidal, with fibrous structure (wood tin); rolled grains (stream tin). Heavy. Colour usually brown to black. Streak, greyish to brownish.	Most important source of tin. Commonly occurs in veins closely associated with granitic rocks or pegmatites. Often in placer deposits.
7. Colour is red or brown — streak is greyish or brownish black			
Bornite Cu_5FeS_4	3	Massive. Colour, bronze-red on fresh surface; tarnishes readily to purple. Streak, greyish black.	A source of copper. Sometimes called 'peacock ore' or 'purple copper ore'.
Pyrrhotite Fe_7S_8	3·5–4	Massive, usually granular. Weakly magnetic. Colour between copper-red and bronze-yellow; tarnishes quickly. Streak, greyish black.	May contain nickel, owing to the presence of pentlandite. Magnetic property distinguishes it from chalcopyrite and pyrite.

Introductory Mineral Table (*cont.*)

A. Minerals with Metallic or Sub-metallic Lustre (*conc.*)

Name and Composition	Hardness	Characteristics	Remarks
7. Colour is red or brown — streak is greyish or brownish black (cont.)			
Wolframite $(FeMn)WO_4$	5–5·5	Granular or lamellar masses; also as crystals, usually striated, and as rolled grains. Perfect cleavage. Heavy. Sometimes weakly magnetic. Colour, reddish brown to black. Streak, dark brownish to black. Fuses easily.	A source of tungsten. Occurs in quartz veins, pegmatites, and granites. Commonly associated with cassiterite and scheelite. Often found in placer deposits.
Niccolite NiAs	5–5·5	Usually massive; rounded or columnar forms common. Heavy. Colour, copper-red, tarnishing quickly to brown. Streak, brownish black.	A source of nickel. Commonly associated with cobalt-nickel arsenides and annabergite (green nickel bloom).

B. Minerals with Non-metallic Lustre[1]

Name and Composition	Hardness	Characteristics	Remarks
1. Colour is white or grey, or the mineral is colourless			
Talc $H_2Mg_3(SiO_3)_4$	1–1·5	Usually foliated or massive. Perfect basal cleavage. Laminae flexible, but not elastic. Greasy feel. Colour commonly white or light green; also grey, dark green or brown. May be easily marked with the finger nail.	Secondary origin. Occurs frequently as talcose schists; often associated with serpentine. Mined at Madoc, Ont. *Soapstone* is a massive variety, sometimes forming extensive beds.
Gypsum $CaSO_4.2H_2O$	2	Granular and foliated masses; platy crystals, often as 'swallow-tail' twins. Perfect cleavage. Glassy to pearly lustre. Colourless or white, often tinted grey, red, or yellow.	In mineral veins and in sedimentary deposits. *Selenite* – colourless, transparent crystals and broad foliae. *Satin spar* – fine-fibrous with silky lustre.
Kaolin $H_4Al_2Si_2O_9$	2–2·5	Massive, usually clay-like or earthy. Pearly to dull lustre. Colour, white, often stained with iron oxides.	Occurs predominantly as decomposition product of feldspars in granites and pegmatites. Also in sedimentary beds.
Muscovite (white mica) Silicate of Al and K	2–2·5	Flakes and scaly or foliated masses. Perfect basal cleavage. Thin flakes flexible and elastic. Usually colourless, pale amber, or light green.	An abundant rock-forming mineral. Commonly found in granites, pegmatites, and schists. Valuable because of its high dielectric constant. May be split easily into thin, transparent flakes.
Brucite $Mg(OH)_2$	2·5	Foliated and fibrous masses; embedded grains; and broad, platy crystals. Foliae flexible. Sectile. Pearly, waxy, or glassy lustre. Transparent to translucent. Colour, white, often tinted grey, blue, or green.	Found in metamorphic limestones and with serpentine and chlorite minerals. Harder than talc.
Halite NaCl	2·5	Massive, with cubic cleavage. Salty taste. Colourless or white; various colours when impure. Soluble in water.	Occurs in sedimentary rocks. Often associated with gypsum.
Calcite $CaCO_3$	3	Cleavable, granular, and compact masses; also as crystals. Perfect rhombohedral cleavage. Colourless or white; also pink or grey; sometimes blue or yellow. Effervesces in cold, dilute, hydrochloric acid.	Widely distributed mineral. Common in metalliferous veins as a gangue mineral. Occurs in sedimentary deposits as limestone, marble, and chalk. Much softer than feldspar.
Barite $BaSO_4$	3–3·5	Columnar, laminated, compact, and earthy masses; platy crystals. Perfect cleavage. Quite heavy. Colour, white; also yellow, brown, red, or grey.	Occurs in sedimentary rocks and in metalliferous veins. Frequently associated with ores of lead and zinc. Heavier than calcite or gypsum. Softer than feldspar.

[1] Minerals of non-metallic lustre have not been sub-classified according to their streak because the majority have either a colourless or light greyish streak, or a streak faintly tinted the colour of the mineral. However, there are a few exceptions, and where the streak is a distinguishing characteristic it is noted in the table. The most notable exceptions are cinnabar, hematite, and limonite.

Introductory Mineral Table (*cont.*)

B. Minerals with Non-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
1. Colour is white or grey, or the mineral is colourless (cont.)			
Celestite $SrSO_4$	3–3·5	Fibrous and granular masses; platy crystals. Perfect cleavage. Quite heavy. Glassy to pearly lustre. Colour, white, sometimes bluish or reddish. Colours blow-pipe flame red.	Occurs mainly in sedimentary rocks; sometimes in veins, associated with galena and sphalerite.
Siderite $FeCO_3$	3·5–4	Cleavable, compact, and botryoidal masses. Perfect rhombohedral cleavage. Colour, greyish or brownish; dark brownish on weathered surface. Effervesces in hot hydrochloric acid.	Occurs in sedimentary and replacement-type deposits, and in metalliferous veins. Heavier than calcite or dolomite.
Dolomite $CaMg(CO_3)_2$	3·5–4	Cleavable, granular, and compact masses; rhombohedral crystals, often curved. Perfect rhombohedral cleavage. Colour, white, grey, or pink. Powder effervesces in warm, dilute, hydrochloric acid.	Occurs in sedimentary rocks and in metalliferous veins. Resembles calcite, but does not effervesce in cold acid.
Scheelite $CaWO_4$	4·5–5	Massive. Quite heavy. Fluoresces. Brilliant lustre. Transparent to translucent. Colour, usually white, yellowish, or brownish.	A source of tungsten. Occurs in pegmatites and ore veins associated with granitic rocks; also in contact metamorphic deposits.
Nepheline $NaAlSiO_4$	5·5–6	Grains or masses. Generally colourless, white or greyish white. Greasy lustre. Poor cleavage. Brittle. Subconchoidal fracture. Gelatinizes with hydrochloric acid. Not found with quartz.	Occurs mainly in silica-deficient alkaline rocks. Not readily recognizable. Factors suggestive in rocks are lack of quartz, pitting of weathered surfaces and greasy lustre. Nepheline syenite used in the glass and whitewear industries.
Feldspar Group Silicates of Al, K, Na, and Ca	6–6·5	Massive, usually cleavable or granular, sometimes lamellar or compact. Two cleavages at, or nearly at, right angles; also less perfect prismatic cleavage. Brittle. Glassy to pearly lustre. Variously coloured but generally white, greyish, or reddish. *Amazonstone* – green.	Abundant rock-forming minerals. Especially common in granites, syenites, gneisses, and pegmatites; also as crystals in porphyries and as a constituent of sands. *Microcline* – commonly reddish; widespread; used in ceramic industry. *Plagioclase* group – usually show fine striations on cleavage surfaces; also play of colours.
Spodumene $LiAl(SiO_3)_2$	6·5–7	Cleavable and columnar masses; prismatic crystals, often vertically striated. Perfect prismatic cleavage. Splintery fracture. Glassy to pearly lustre. Colour, white, greyish, or greenish. Fuses easily, colouring flame purple-red.	A source of lithium. Occurs in granite pegmatites, sometimes as very large crystals.
Quartz SiO_2	7	Massive, often as formless glassy grains; hexagonal crystals. Conchoidal fracture. Glassy lustre. Transparent to opaque. Colourless or variously coloured. *Milky* – milky-white; *rose* – pink; *amethyst* – violet; *smoky* – brown to black.	Most common mineral. Especially abundant in granites, gneisses, quartzites, sandstones, and sands. Also very common as a vein mineral. Cryptocrystalline varieties include *flint, chert, chalcedony, agate* (banded), and *jasper* (red).
Zircon $ZrSiO_4$	7·5	Usually as small, square, elongated crystals with pyramidal ends. Brilliant lustre. Colourless, yellowish, greyish, or brownish.	Common accessory constituent of igneous rocks, especially granites. Also in pegmatites and sands. *Cyrtolite* contains rare earths.
Corundum Al_2O_3	9	Barrel-shaped crystals common; also massive, with rectangular parting. Frequently striated. Colour, grey, brown, blue, red, or yellow.	Important amounts found in syenite and nepheline syenite. Gem varieties include *sapphire* (blue), and *ruby* (red).

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **apatite, amphibole, pyroxene, kyanite, olivine,** *and* **beryl.**

Introductory Mineral Table (*cont.*)

B. Minerals with Non-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
2. Colour is blue, green, or violet			
Talc $H_2Mg_3(SiO_3)_4$	1–1·5	Usually foliated or massive. Perfect basal cleavage. Laminae flexible, but not elastic. Greasy feel. Colour commonly light green or white; also grey, dark green or brown. May be easily marked with the finger nail.	Secondary in origin. Occurs frequently as talcose schists; often associated with serpentine. Mined at Madoc, Ont. *Soapstone* is the massive variety, sometimes forming extensive masses.
Chlorite Hydrous silicate of Al, Fe, and Mg.	2–2·5	Commonly in scaly, dense, or earthy masses. Perfect cleavage. Thin flakes flexible but not elastic. Colour usually greenish	Usually occurs as a secondary mineral. Often associated with amphibole, pyroxene, biotite, and serpentine. Common as chlorite schists. Distinguished from micas by greenish colour and inelasticity of flakes.
Annabergite (nickel bloom) $Ni_3As_2O_8.8H_2O$	2·5–3	Usually as stains or earthy crusts. Colour, apple-green. Streak, light green.	Secondary in origin. Indication of nickel-bearing minerals, from which it is formed.
Serpentine $H_4Mg_3Si_2O_9$	2·5–4	Usually massive; sometimes foliated. Smooth to greasy feel. Waxy to greasy lustre. Colour, pale to dark green, yellowish, or brownish. Powder yields water when ignited in closed tube. *Chrysotile* (asbestos) – delicately fibrous. Fibres flexible and easily separable. Silky lustre. Colour usually greenish white.	Secondary mineral. Commonly associated with olivine, pyroxene, and amphibole. Also forms large masses by alteration of basic rocks. *Chrysotile* usually occurs in veinlets in massive serpentine.
Azurite $2CuCO_3.Cu(OH)_2$	3·5–4	Stains and fibrous crusts; also as botryoidal masses and as crystals. Colour, light blue to dark blue. Streak, light blue. Effervesces in hydrochloric acid.	Secondary mineral. Almost always associated malachite. Indication of primary copper-bearing minerals.
Malachite $CuCO_3.Cu(OH)_2$	3·5–4	Stains and fibrous crusts; banded, botryoidal masses; and earthy. Colour usually bright green. Streak, light green. Effervesces in hydrochloric acid.	Secondary mineral. Indication of primary copper-bearing minerals.
Fluorite CaF_2	4	Granular and compact masses; cubic crystals. Octahedral cleavage. Fluoresces. Colour commonly greenish, bluish, yellowish, or violet.	Occurs in sedimentary and igneous rocks; in pegmatites; and as a vein mineral, often associated with ores of lead, silver, and zinc.
Apatite $Ca_5(PO_4)_3(F,Cl,OH)$	4·5–5	Hexagonal crystals; also granular, compact, and nodular masses. Brittle. Glassy to resinous lustre. Colour usually greenish; sometimes brown, red, blue, or grey.	Found in most types of rocks. Common in contact metamorphic limestones and in pegmatites. Also occurs as extensive sedimentary deposits. Softer than beryl.
Amphibole Group Silicates of, chiefly, Ca, Mg, and Fe	5–6	Granular, columnar, and fibrous masses; prismatic crystals, stubby or bladed. Two cleavages, meeting at angles of 56° and 124°. Colour, greyish green through green to black; also white or grey.	Abundant rock-forming minerals. *Tremolite* and *actinolite* usually grey to green; common in metamorphic limestones, schists, and gneisses. *Hornblende* usually dark green to black; common constituent of igneous rocks. Cleavage distinguishes amphibole from pyroxene.
Pyroxene Group Silicates of, chiefly, Ca, Mg, and Fe	5–6	Granular and lamellar masses; prismatic crystals, square or eight-sided. Two cleavages, almost at right angles. Colour usually light to dark green to black; also white or grey.	Very common rock-forming minerals. *Diopside* — light green; found in contact metamorphic limestones and dolomites. *Augite* — dark green to black; common in dark-coloured igneous rocks. Cleavage distinguishes pyroxene from amphibole.
Kyanite Al_2SiO_5	5–7	Coarsely bladed or columnar masses; long-bladed crystals. Perfect cleavage. Glassy lustre. Colour usually bluish; also white, greyish, or greenish.	Occurs mainly in schists and gneisses. Often associated with garnet.
Epidote $HCa_2(AlFe)_3Si_3O_{13}$	6–7	Granular, fibrous, and compact masses; elongated prismatic crystals, deeply striated. Perfect cleavage. Glassy lustre. Colour, pistachio green to greenish black. Fuses easily.	Metamorphic mineral. Common alteration product of feldspars.

Introductory Mineral Table (*cont.*)

B. Minerals with Non-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
2. Colour is blue, green or violet (cont.)			
Olivine $(MgFe)_2SiO_4$	6·5–7	Usually as disseminated grains or granular, sugar-like masses. Good cleavage. Glassy lustre. Colour usually olive-green; sometimes yellowish, greyish, or brownish.	Occurs in basic igneous rocks such as peridotite, diabase, and gabbro, where often associated with chromite, magnetite, and spinel; also found in metamorphosed limestones and dolomites.
Spodumene $LiAl(SiO_3)_2$	6·5–7	Cleavable and columnar masses; prismatic crystals, often vertically striated. Perfect prismatic cleavage. Splintery fracture. Glassy to pearly lustre. Colour, greenish white or greyish white. Fuses easily, colouring flame purple-red.	A source of lithium. Occurs in granite pegmatites, sometimes as very large crystals.
Beryl $Be_3Al_2(SiO_3)_6$	7·5–8	Usually as prismatic crystals with hexagonal cross-section; occasionally massive. Glassy lustre. Colour generally pale greenish; also bluish, greyish, or white.	Principal source of beryllium. Commonly found in pegmatites. Some transparent varieties valuable as gem stones; these include *emerald* (green), and *aquamarine* (bluish green).
The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **muscovite, brucite, halite, calcite, celestite, feldspar** (*var. amazonstone*), **garnet, quartz** (*var. amethyst*), **tourmaline, spinel,** *and* **corundum.**			
3. Colour is pink, red, or reddish brown			
Erythrite (cobalt bloom) $Co_3As_2O_8.8H_2O$	1·5–2·5	Usually as stains or earthy crusts; sometimes botryoidal. Colour, peach-red to crimson red. Streak, pale red. In closed tube yields water and turns bluish at low heat.	Secondary mineral. Indication of cobalt-bearing minerals, from which it is formed.
Cinnabar HgS	2–2·5	Earthy coatings; crystalline crusts; and massive. Heavy. Colour, bright red. Streak, scarlet. On being heated in open tube, it produces sulphurous fumes and minute globules of mercury.	Principal source of mercury. Resembles some varieties of hematite, but distinguished by heating test.
Monazite Phosphate of the cerium group of rare earths, chiefly, and thorium	5–5·5	Usually as wedge-shaped crystals or rounded, embedded grains; also as rolled grains in placers. Good cleavage. Brittle. Radioactive. Resinous lustre. Colour commonly clove-brown, reddish or yellowish brown.	A source of rare earths and thorium oxide. Occurs chiefly in pegmatites and placer deposits.
Titanite $CaTiSiO_5$	5–5·5	Commonly as flattened, wedge-shaped crystals; sometimes massive or disseminated. Glassy lustre. Colour generally reddish brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Hematite Fe_2O_3	5·5–6·5	Compact, granular, botryoidal, and earthy masses. Colour, reddish brown to steel-grey. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite* has a micaceous structure with a splendent lustre.
Feldspar Group Silicates of Al,K,Na, and Ca	6–6·5	Massive, usually cleavable or granular, sometimes lamellar or compact. Two cleavages at, or nearly at, right angles; also less perfect prismatic cleavage. Brittle. Glassy to pearly lustre. Variously coloured but generally reddish, greyish, or white. *Amazonstone* – green.	Abundant rock-forming minerals. Especially common in granites, syenites, gneisses, and pegmatites; also as crystals in porphyries and as a constituent of sands. *Microcline* — commonly reddish; widespread; used in ceramic industry. *Plagioclase* group — usually show fine striations on cleavage surfaces; also play of colours.
Garnet Group Complex silicates of, chiefly, Al, Ca, Mg, Fe, and Mn.	6·5–7·5	Commonly as dodecahedral crystals; also as granular or lamellar masses. Conchoidal fracture. Glassy lustre. Transparent to translucent. Colour commonly red, brown, or black.	Widely distributed minerals. Common as isolated crystals in schists. Also occurs as an accessory constituent in granitic and contact metamorphic rocks. Used as an abrasive.
The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **gypsum, halite, calcite, dolomite, phlogopite, celestite, apatite, quartz** (*var. rose*), **zircon, spinel,** *and* **corundum.**			

Introductory Mineral Table (*cont.*)

B. Minerals with Non-metallic Lustre (*cont.*)

Name and Composition	Hardness	Characteristics	Remarks
4. Colour is yellow, yellowish brown, or brown			
Ferrimolybdite (molybdenum stain) $Fe_2(MoO_4).8H_2O$	1 · 5	Usually as stains or earthy crusts. Colour, canary yellow. Streak, pale yellow.	Secondary mineral, formed by the alteration of molybdenite. Frequently associated with limonite. May be confused with uranium stain (which follows).
Uranium stain Hydrous silico-uranates of Ca, Pb, etc.	to 3	Commonly as stains or dense coatings. Radioactive. Fluoresces. Lustre greasy to dull. Colour usually yellow to orange.	Uranium stain is a general term used to describe the brightly coloured secondary uranium minerals occurring at or near uranium deposits.
Limonite $2Fe_2O_3.3H_2O$	to 5 · 5	Massive, usually in botryoidal and stalactitic forms with fibrous structure; sometimes earthy. Colour, yellowish to dark brown. Streak, yellowish brown.	Secondary mineral. Common as rust-like stains on weathered rocks. Distinguished from hematite by its streak. *Bog iron ore* occurs in marshy places; porous texture.
Phlogopite (amber mica) Silicate of Al, K and Mg.	2 · 5–3	Commonly in disseminated flakes; also as crystals, usually hexagonal in outline. Perfect basal cleavage. Thin flakes flexible and elastic. Colour, pale amber to brownish red.	Found mainly in crystalline limestones and dolomites, and in schists. This association serves to distinguish it from muscovite. May be split easily into thin, transparent flakes.
Siderite $FeCO_3$	3 · 5–4	Cleavable, compact, and botryoidal masses. Perfect rhombohedral cleavage. Colour, brownish or greyish, dark brownish on weathered surface. Effervesces in hot hydrochloric acid.	Occurs in sedimentary and replacement-type deposits, and in metallic veins. Heavier than calcite or dolomite.
Sphalerite ZnS	3 · 5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, yellow, brown, or black. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Scheelite $CaWO_4$	4 · 5–5	Massive. Quite heavy. Fluoresces. Brilliant lustre. Transparent to translucent. Colour usually yellowish, brownish, or white.	A source of tungsten. Occurs in pegmatites and ore veins associated with granitic rocks; also in contact metamorphic deposits.
Thorite $ThSiO_4$	4 · 5–5	Usually as small crystals, resembling zircon in form; also as rounded grains. Radioactive. Resinous lustre. Colour, yellowish, orange, brown or black.	Commonly found in pegmatites and associated rocks.
Monazite Phosphate of the cerium group of rare earths, chiefly, and thorium.	5–5 · 5	Usually as wedge-shaped crystals or rounded, embedded grains; also as rolled grains in placers. Good cleavage. Brittle. Radioactive. Resinous lustre. Colour commonly clove-brown, reddish or yellowish brown.	A source of rare earths and thorium oxide. Occurs chiefly in pegmatites and placer deposits.
Pyrochlore–microlite Group Niobates and tantalates of Ca, Na,U,Th, and rare earths.	5–5 · 5	Commonly in rounded grains and octahedral crystals. Radioactive. Glassy, resinous, or waxy lustre. Colour, yellow to brown to black. Streak, yellowish brown.	Found in pegmatites and in carbonatites and silicate rocks of alkaline complexes.
Titanite $CaTiSiO_5$	5–5 · 5	Commonly as flattened, wedge-shaped crystals; sometimes massive or disseminated. Glassy lustre. Colour generally brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Zircon $ZrSiO_4$	7 · 5	Usually as small, square, elongated crystals with pyramidal ends. Brilliant lustre. Colour, yellowish, greyish, or brownish; sometimes colourless.	Common accessory constituent of igneous rocks, especially granites. Also in pegmatites and sands. *Cyrtolite* contains rare earths.
The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **talc, gypsum, kaolin, halite, serpentine, calcite, barite, fluorite, apatite, uranothorite, allanite, olivine, spinel,** *and* **corundum.**			
5. Colour is greenish black, brownish black, or black			
Biotite (black mica) Silicate of Al, K, Mg, and Fe.	2 · 5–3	Flakes and scaly masses. Perfect basal cleavage. Thin flakes flexible and elastic. Splendent lustre. Colour generally black.	Very common rock-forming mineral. Found in igneous and metamorphic rocks, such as granite, syenite, diorite, and gneisses, and in pegmatites. May be split easily into thin black flakes.

Introductory Mineral Table (*conc.*)

B. Minerals with Non-metallic Lustre (*conc.*)

Name and Composition	Hardness	Characteristics	Remarks
5. *Colour is greenish black, brownish black or black (cont.)*			
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, black, brown, or yellow. Streak, brownish to light yellow and white.	Most important ore of zinc. Usually closely associated with galena.
Thorite $ThSiO_4$	4·5–5	Usually as small crystals, resembling zircon in form; also as rounded grains. Radioactive. Colour, black, brown, orange, or yellowish.	Commonly found in pegmatites and associated rocks.
Uranothorite Hydrous silicate of Th, chiefly, and U.	4·5–5	Elongated, square, prismatic crystals, sometimes very slender; also as rounded masses and grains. Radioactive. Pitchy lustre. Colour, generally black; also reddish or yellowish.	Commonly found in pegmatites and related rocks.
Pyrochlore–microlite Group Niobates and tantalates of Ca, Na, U, Th, and rare earths.	5–5·5	Commonly in rounded grains and octahedral crystals. Radioactive. Glassy, resinous, or waxy lustre. Colour, black, brown or yellow. Streak yellowish brown.	Found in pegmatites and in contact metamorphic deposits.
Titanite $CaTiSiO_5$	5–5·5	Commonly as flattened, wedge-shaped crystals; sometimes massive and disseminated. Glassy lustre. Colour generally reddish brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Amphibole Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular, columnar, and fibrous masses; prismatic crystals, stubby or bladed. Two cleavages, meeting at angles of 56° and 124°. Colour commonly greenish to black.	Abundant rock-forming minerals. *Hornblende,* usually dark green to black; common constituent of igneous rocks. Cleavage distinguishes amphibole from pyroxene.
Pyroxene Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular and lamellar masses; prismatic crystals, square or eight-sided. Two cleavages, almost at right angles. Colour commonly greenish to black.	Very common rock-forming minerals. *Augite,* dark green to black; common in dark-coloured igneous rocks. Cleavage distinguishes pyroxene from amphibole.
Allanite Silicate of, chiefly, rare earths Ca, Fe, and Al.	5·5–6	Massive and as embedded grains; platy crystals. Brittle. Radioactive. Pitchy to glassy lustre. Colour, black, but alters readily to brown. Fuses easily to a black magnetic glass.	Found in granitic rocks and pegmatites; also in metamorphic rocks. Sometimes associated with magnetite. Radioactivity is caused chiefly by thorium.
Epidote $HCa_2(AlFe)_3Si_3O_{13}$	6–7	Granular, fibrous, and compact masses; elongated prismatic crystals, deeply striated. Perfect cleavage. Glassy lustre. Colour, pistachio green to greenish black. Fuses easily.	Metamorphic mineral. Common alteration product of feldspars.
Garnet Group Complex silicates of, chiefly, Al, Ca, Mg, Fe, and Mn.	6·5–7·5	Commonly as dodecahedral crystals; also as granular or lamellar masses. Conchoidal fracture. Glassy lustre. Transparent to translucent. Colour commonly brown, red, or black.	Widely distributed minerals. Common as isolated crystals in schists. Also occur as accessory constituents in granitic and contact metamorphic rocks. Used as an abrasive.
Quartz variety *smoky* SiO_2	7	Usually massive. Conchoidal fracture. Glassy lustre. Transparent to opaque. Colour, smoky-brown to brownish black.	Common in granites and pegmatites.
Tourmaline Complex silicate of B and Al with Mg, Fe, etc.	7–7·5	Commonly as prismatic crystals, vertically striated, with triangular cross-section; also massive. Brittle. Colour usually black, sometimes red, blue, or green. Some varieties fuse easily.	Common in pegmatites; also in granites and gneisses. Some varieties used as gem stones.
Spinel $MgAl_2O_4$	8	Octahedral crystals, often twinned; also as granular masses and as embedded grains. Brittle. Transparent to opaque. Glassy lustre. Colour, black, green, brown, or red.	Found mainly as an accessory constituent of basic igneous rocks, and as a metamorphic mineral in schists and crystalline limestones.

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **chlorite, serpentine,** *and* **corundum.**

APPENDIX V

Field Classifications of Common Rocks

1. Igneous Rocks[1]

Amount of Quartz	Proportion of Potash Feldspar to total Feldspar	More than 10% Feldspar — Composition of Plagioclase: Albite An_0 — An_{10}	Oligoclase An_{10} — An_{30}	Andesine An_{30} — An_{50}	Labradorite, etc. An_{50} — An_{100}	Less than 10% Feldspar	Monomineralic[2] Commonly less than 10% extraneous minerals
More than 10% Quartz	More than ⅔	**GRANITE** *RHYOLITE*					
	⅓-⅔		**QUARTZ MONZONITE** *QUARTZ LATITE*				
	Less than ⅓	**ALBITE GRANITE** *RHYOLITE*	**GRANODIORITE** *QUARTZ LATITE*	**QUARTZ DIORITE** *DACITE*	**QUARTZ GABBRO** *QUARTZ BASALT*		
Less than 10% Quartz	More than ⅔	**SYENITE** *TRACHYTE*				PERKNITE PERIDOTITE (More than 5% Olivine)	PYROXENITE HORNBLENDITE DUNITE ANORTHOSITE
	⅓-⅔		**MONZONITE** *LATITE*				
	Less than ⅓	**ALBITE SYENITE** *TRACHYTE*	**SYENODIORITE** *LATITE*	**DIORITE** *ANDESITE*	**GABBRO** *BASALT*		

COMMON CONTENT OF DARK MINERALS

0 — 10	10 — 40	40 — 70	70 — 100

GENERAL TERMS FOR FINE-GRAINED ROCKS

FELSITE (*light coloured on fresh surface*) TRAP (*dark coloured on fresh surface*)

1 Table from I. C. Brown and officers of the Geological Survey of Canada.
2 Rocks consisting almost entirely of a single mineral.
Note: Names of coarser grained (plutonic) rocks are boldface, and those of finer grained rocks (dyke and volcanic rocks) are lightface.

2. Common Sedimentary Rocks

Origin	Unconsolidated Source	Consolidated Rock	Characteristics
Mechanical	Gravel	Conglomerates	Gravels consist of fragments of rocks and minerals of various kinds and sizes. They are fairly rounded. A conglomerate consists of such an assemblage cemented by deposition of minerals between fragments. Breccia has angular fragments instead of rounded ones.
	Till	Tillite	Unsorted glacial material.
	Sand	Sandstone	Sands consist of fairly well rounded grains of minerals or rocks, usually only a few millimetres in diameter. Ordinarily quartz is the most abundant mineral but the term sand has reference to the grain size, not to the kind of grain. A sandstone is a quartz sand cemented by deposition of minerals around the grains. The cementing mineral may be quartz, calcite, iron oxide, or even bituminous material. A rock composed mainly of grains of feldspar is called arkose.
	Silt	Siltstone	Formed of particles intermediate in size between sand and clay.
	Clay	Shale	Clay is made up of tiny flakes of kaolin and similar minerals. When it becomes consolidated the rock is a shale.
Chemical		Salt, gypsum	Formed by evaporation of water of salt lakes.
		Chert, some limestones and dolomites	Formed by loss of carbon dioxide (CO_2) from solutions containing the bicarbonate. Chert is probably formed by coagulation of colloidal silica.
		Bog iron	Formed by coagulation of colloidal solutions of iron. Iron secreting bacteria may be instrumental.
		Most limestone	Formed mainly or entirely from chemical deposition of calcium carbonate.
Organic		Some limestones	Formed of shells, or fragments of shells.

3. Metamorphic Rocks[1]

A. From Sediments

Original rocks	Affected by	Physical character	Metamorphic rock
Quartz sands and sandstones	heat or pressure and solutions; differential pressures	cemented	quartzite
		schistose	quartz schist
Impure sands and sandstones	heat or pressure and solutions; differential stress	cemented	arkose
		schistose or gneissic	paragneiss
Mud and shale	heat or pressure and solutions; differential stress	dense appearance and fine grained	staurolite, chloritoid, and andalusite schists; slate, phyllite, and chlorite schist
Limestone	all agents	recrystallized	marble

B. From Igneous Rocks

Granite, syenite, diorite, gabbro	differential stress	foliated	orthogneiss
Rhyolite and trachyte	differential stress	foliated	quartz–sericite schists, and sericite schists
Andesite and basalt	uniform pressure and solutions; differential stress	massive	greenstone
		schistose	chlorite schist, talc schist, actinolite schist, hornblende schist

1 Tables from Mining Textbook No. 1, Canadian Legion Educational Services.

4. Simplified Classification of Metamorphic Facies*

Increasing Temperature →

Increasing Pressure ↓				
				Sanidinite facies
	Greenschist facies	Epidote–amphibolite facies	Amphibolite facies	Pyroxene–hornfels facies
				Granulite facies
		Glaucophane schist facies		Eclogite facies

From Spock, L. E.: *Guide to the Study of Rocks*, 2nd ed., 1962 (Harper), after Eskola.
* Not entirely a field classification

APPENDIX VI

Some Equipment and Tests for Identifying Minerals

A few minerals can be identified by sight or feel alone, or with the additional evidence of a scratch with a pointed object. Many other minerals can be identified with the help of simple equipment or fairly simple chemical tests that are explained here and are used in combinations of two or more tests. Other minerals can be positively identified only by laboratory tests that are beyond the scope of prospecting; in many cases, however, conventional prospectors and advanced prospectors can make tests in the field for the presence of metal even if the mineral itself cannot be identified. At times this may be more important than the identification.

Many of the minerals encountered in the field can be identified, or narrowed down to a few possibilities, by physical tests, which should be given most attention. Ordinary chemical and blowpipe tests are not a substitute for physical tests but may be needed to supplement them. Particularly in the case of blowpiping, care and patience and, if possible, some instruction is required. The tests outlined here stress ordinary 'wet' chemical tests rather than blowpiping, but the latter may be desirable at times.

The following equipment can be obtained in small ready-made kits or purchased separately. The equipment and reagents can be obtained from dealers in laboratory supplies, whose addresses can be found in city telephone directories. Some can also be obtained from dealers in mineral specimens or prospecting supplies, or from hardware or drug stores.

Apparatus

Magnet

This is used to distinguish the magnetic minerals, such as magnetite, ilmenite, pyrrhotite, etc. Magnets are available in a variety of sizes and shapes, but probably the most suitable is a horseshoe-shaped magnet about 1½ inches in width. Many persons prefer one made of a special alloy called alnico, but an ordinary steel magnet will serve equally well.

Pocket-knife

A pocket-knife is indispensable to a prospector for many reasons. It is mentioned here because it is useful for determining the hardness of minerals. The blade has a hardness value of between 5 and 6. (*See also* Appendix IV, footnote 2). Rather than carry a magnet, some prospectors find it convenient to magnetize one blade of their pocket-knife. This may be done by stroking the blade of the knife slowly and in one direction with a hand magnet.

Streak Plate

This is a piece of white unglazed porcelain that is used to determine the streak of the mineral. The streak is the colour of the finely powdered mineral; it may be produced quickly by rubbing the mineral across a streak plate.

File

A small triangular file is used for nicking glass tubing before breaking, and may also be used to determine the streak and hardness of minerals. The streak is determined by filing an edge off the mineral and collecting the powder. The hardness value of the file is between 6 and 7. A fine flat file may be used like a streak plate.

Hand Lens

A hand lens is necessary for examining small mineral grains, and for studying closely such properties as cleavage and twinning. A simple magnifying lens, 1½ inches in diameter and with a magnifying power of 3½, is adequate. The lens should be protected by a chamois bag.

Lamp

The lamp is an essential piece of apparatus for many tests. If gas is available, the Bunsen burner is the most convenient type of lamp to use, as it provides a hot flame, and may be regulated. A special tip is inserted for blowpiping. When gas is not available, an alcohol lamp with a wick is probably the most satisfactory for heating test tubes. An alcohol flame does not contain enough carbon to produce good blowpipe flames. For this purpose a candle or a special lamp that burns paraffin or olive oil is better. They deposit soot when used to heat test tubes but are otherwise satisfactory.

Blowpipe

This is a curved, slender metal tube about seven inches long that is used to concentrate the lamp flame at a point. The tube is drawn to a fine tip at one end, and some are fitted with a mouthpiece at the larger end. Some blowpipes are made with a small bulb near the centre for catching moisture.

Glass Tubes

These should be 4 to 5 inches long, about 3/16 inch in diameter, and made of hard glass. They are useful for determining the presence of water and volatile constituents such as sulphur, arsenic, and antimony. This is done by heating a little of the powdered mineral in the tube in the blowpipe flame. The tubes may be open at both ends, or closed at one end. Open tubes are commonly bent to keep a sample from dropping out (*see* Pl. 87A). The closed tube is especially useful for determining the presence of water.

Test Tubes

A few small test tubes would normally be used for chemical tests, but discarded cups, small glasses, or other glass or china containers would serve.

Charcoal Blocks

Small rectangular blocks of charcoal are useful for studying the reactions of minerals under the blowpipe flame. Charcoal made from basswood or pine is recommended, but any kind of charcoal that will not splinter on heating is suitable. The blocks can be purchased or improvised. Plaster of Paris slabs are used for some tests but would not be required, at least at first.

Reagents

Chemical compounds and elements used in tests are called reagents. The following would be a reasonable selection to begin with, and others could be obtained if necessary. Unless otherwise noted, about 4 ounces of liquid reagents, including concentrated acids, might be suitable, and one ounce of dry reagents. Unless a dealer suggests otherwise stoppers should be glass, except for strong caustics that may require rubber stoppers to prevent sticking. Stoppers should be held in place by tape or wax, when travelling, and bottles should be packed upright. *Some of the reagents are poisonous or corrosive, so all should be kept away from children, food, and cooking utensils, and handled carefully particularly with respect to the eyes and mouth. Some fumes, such as those of mercury and arsenic, should not be breathed.*

Dry Reagents

Borax

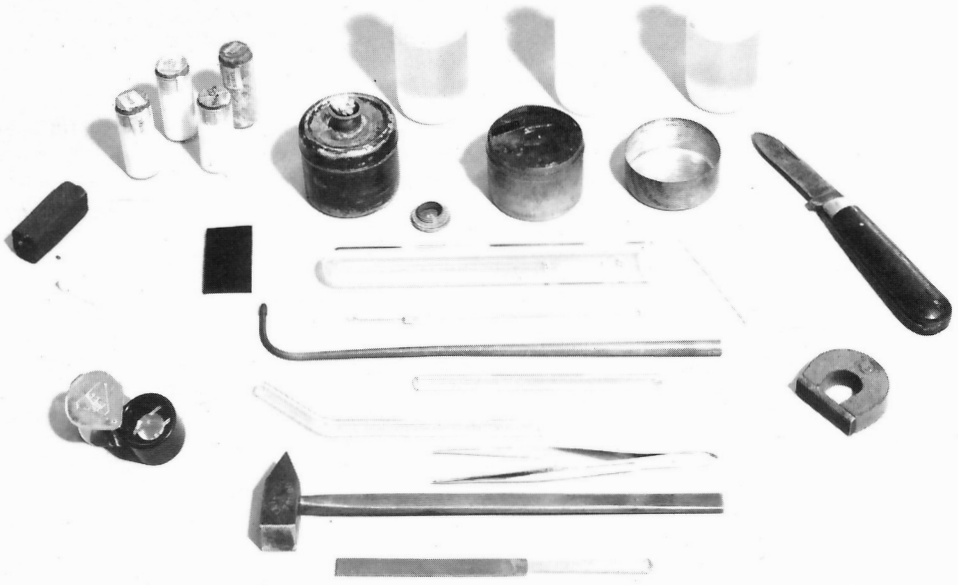
Cobalt nitrate. Dissolve crystals in about 10 parts of water for use.

Dimethylglyoxime. ½ ounce. For use dissolve in about 70 parts of ethyl alcohol.

Hydrogen sodium ammonium phosphate (salt of phosphorous or microcosmic salt).

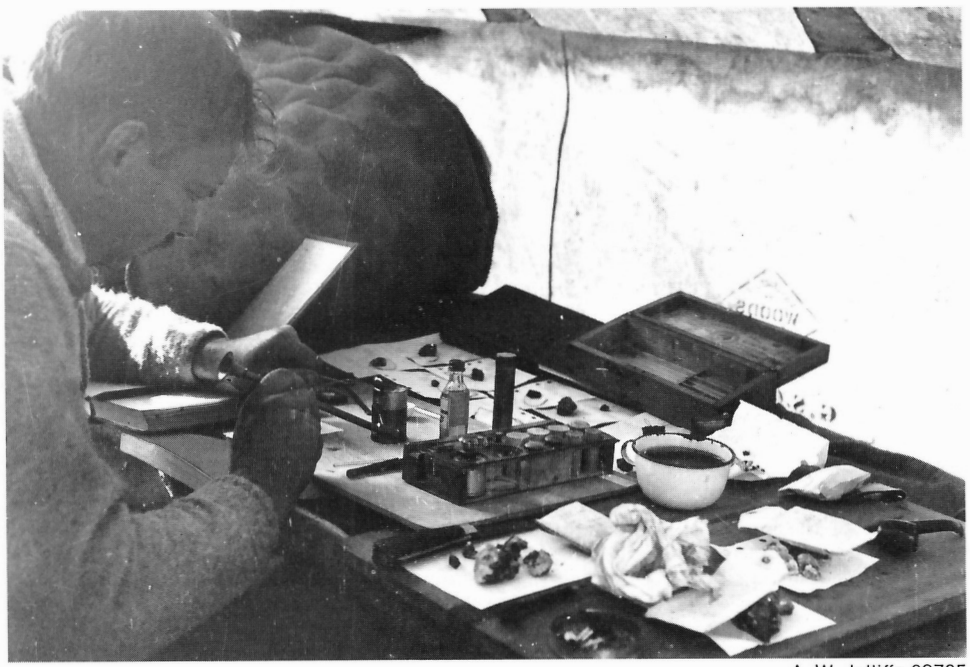
Potassium chlorate. One or two pounds might be used, but would not be essential, for testing sulphide minerals for gold.

Plate 87



A. Blowpiping and other equipment for identifying minerals, including alcohol lamp, blowpiping lamp, test tube, platinum-wire loop, mouth-blowpipe, closed tube, and open tube.

F. J. Cooke 200889A



B. Blowpiping in the field.

A. W. Jolliffe 93795

Potassium iodide.
Sodium carbonate (soda ash)
Sodium fluoride
Granulated tin
Granulated zinc (small fragments of the metal parts of flashlight batteries will do).

Wet Reagents
Ammonium hydroxide (sometimes called ammonia but not the same as powdered household ammonia). Dilute with two parts of water for use.

Hydrochloric acid. For most tests dilute 2 parts acid to 3 parts of water. Dilute hydrochloric acid (1 part acid to about 4 parts water) is used for testing calcite and limestone and may be carried in the pocket in a small bottle with a glass dropper kept tightly closed.

Nitric acid. For most use dilute 1 part acid to 2 parts water.

Sulphuric acid. For most use dilute 1 part acid to 6 parts water. ***Be sure to add the acid to the water little by little, not vice versa.***

Hydrogen peroxide. Use 3 per cent solution commonly sold in

stores. It is best to buy a few of the smallest bottles and to discard soon after use, as it decomposes after opening.

Water. Used for diluting reagents and washing test tubes, etc. Distilled or rain water is best but any water that is not too 'hard' will do.

Physical Tests

Colour

The colour of some minerals is useful in identification but is not an infallable criterion because, although some minerals occur typically in one or two colours, others may occur in several colours. The usefulness of colour in identification seems to increase with experience.

Streak

The 'streak' is the colour of the powdered mineral, and is often more diagnostic than the colour of the mineral itself. The best way to observe the streak is by rubbing the mineral across a 'streak-plate' of unglazed porcelain, but any means of obtaining a little of the powdered mineral will suffice, such as by scratching or powdering the specimen or rubbing it across a fine file.

Malleability

Some minerals such as gold, native silver, and native copper can be flattened by hammering and are said to be malleable.

Transparency and Opaqueness

These characteristics sometimes help in narrowing down the groupings of minerals.

Lustre

The principal kinds of lustre are 'metallic' and 'non-metallic'. The latter are divided by mineralogists into 'vitreous' (like broken glass), 'adamantine' (brilliant), 'resinous', 'pitchy', 'dull', and other kinds.

Fluorescence

Many minerals produce a different colour than normal when viewed in light from a fluorescent source. These colours vary so greatly according to impurities in the mineral that the main use of fluorescence in identification is to divide minerals into two broad groups: fluorescent and non-fluorescent. A further use is in testing 'beads' produced by blowpiping. Many museums and some other places have displays where persons can obtain an idea of fluorescence.

Radioactivity

Radioactivity detected with a Geiger or scintillation counter indicates minerals containing uranium or thorium, but only special instruments permit distinguishing these two elements by radioactive means. Potassium is weakly radioactive.

Hardness

The relative hardness of minerals is one of the most useful ways of dividing them into broad groups. For comparative purposes a list of ten minerals was adopted as standards, the higher the number, the harder the mineral. They are:

1. Talc	6. Orthoclase
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

A mineral that can be scratched by a corner of a piece of quartz, and which will itself scratch orthoclase has a hardness between orthoclase and quartz and might be considered 6½. Laboratory instruments permit determinations to close limits but reference to the hardness of the following substances and their hardness values is sufficient for most purposes: thumb-nail, 2½; copper coin, 3; knife blade, 5½ to 6; window glass, 5½ to 6; quartz, 7; emery wheel or paper, 8 to 9; carborundum, 9½; glazier's diamond point, 10. After practice, hardness can usually be estimated satisfactorily with a knife-point alone.

Cleavage

Many minerals have a property called cleavage which permits them to be split along parallel planes. Cleavage is commonly designated as 'perfect' (as for mica), 'distinct', 'indistinct' or 'imperfect'. Minerals may have cleavages in more than one direction, in which case the cleavage in one direction may be more pronounced than that in another.

Fracture

The way in which a specimen breaks is often helpful in identification. The most common kinds of fracturing are 'uneven' (breaking into rough, irregular surfaces); 'hackly' (having sharp, jagged edges); splintery; earthy; and conchoidal (breaking into curved, often concentric surfaces).

Fusibility

Ease or difficulty in melting may be a useful criterion.

Smell

Arsenide minerals sometimes emit a garlic-like odour when hammered. Sulphide minerals when heated emit fumes smelling of sulphur, and some chemical tests produce hydrogen sulphide that has a sickening odour like that of rotten eggs. The clay minerals in argillaceous rocks, and in some kinds of alteration around mineral deposits, have a characteristic clayey smell when breathed upon.

Feel

Some minerals are characterized by soft, soapy, or greasy sensations when stroked by a finger.

Magnetism

Strongly magnetic minerals will affect the needle of a compass or be attracted to a magnet. Less magnetic minerals, when powdered, are attracted to a magnet or magnetized knife blade. The powder should be placed on a piece of paper and the magnet applied beneath the paper and moved from side to side, or the magnet may be wrapped in paper and drawn through the powder; otherwise the magnet may be difficult to rid of the powder.

Weight

Some minerals such as those of lead and uranium are so much heavier than most minerals that the hefting of specimens is one clue to their identity. The exact relative weight or 'specific gravity' is related to the weight of water and measured with equipment of various kinds that is unnecessary for most prospectors. One use in connection with beryl is mentioned later under 'chemical tests'.

Crystal Form

Elementary crystal forms are commonly useful clues for identification. Crystal boundaries are referred to three or four axes that may be of similar, or of different, proportions. All axes may be at right angles to one another, two may be at right angles and the other inclined, or all may be inclined. The six primary systems of crystallization are:

1. *Isometric*: (of which the cube is the simplest form): having three axes of equal length, and at right angles to one another. Other common forms are tetrahedrons (4 sides), octahedrons (8 sides), and dodecahedrons (12 sides).
2. *Tetragonal*: having three axes at right angles, two being of equal length and the other different.
3. *Hexagonal*: having three axes of equal length at 60° to one another and in the same plane, and a fourth axis of different length and at right angles to the other three. Quartz crystals are common examples.
4. *Orthorhombic*: having three axes at right angles, all being of different lengths.
5. *Monoclinic*: having three axes of different lengths, two being inclined to each other and the third at right angles to these.
6. *Triclinic*: having three unequal axes, all being inclined to one another.

Chemical Tests

Most of the following tests can be made with simple equipment and supplies. If necessary discarded china cups or saucers or other vessels could be used instead of test tubes. Many tests can be done without the aid of a blowpipe. Others require elementary blowpiping, for which some instruction is desirable. Advanced blowpiping techniques are not as popular as they once were because they require a good deal of care, time, and experience and have to some extent been superseded by the development of simple methods that were not known when blowpiping was popular. Still, some prospectors may benefit from learning more about it than is contained here.

A blowpipe flame is an ordinary flame made hotter by blowing air into it from the mouth. To produce a steady flame the cheeks are blown out to allow air to be expelled while the nose is used for inhaling. For chemical tests the flame is blown sideways or slightly downward. These flames are of two kinds: oxidizing (adding oxygen to the sample) and reducing (removing oxygen from the sample). An oxidizing flame is produced by inserting the tip of the pipe slightly into the flame. A reducing flame is produced by placing the tip just outside the flame and blowing very gently.

Antimony

A dense white bloom (sublimate) forms on charcoal when a fragment of mineral containing this element is heated on it with an oxidizing flame.

Arsenic

When heated, minerals containing much arsenic emit white fumes that smell like garlic. Some arsenical minerals, when heated in a closed tube, form a black mirror-like coating inside the tube.

Beryllium

Beryl, the chief mineral of beryllium, is not adaptable to simple tests and, if pale coloured, may be difficult to distinguish from quartz. A test that may be useful at times is based on the different specific gravities of beryl and quartz or feldspar. Small, even-sized fragments of beryl and of quartz or feldspar are dropped into a tube containing bromoform or acetylene tetrabromide. A little benzene is carefully poured on top, and the tube is left undisturbed for several hours. This forms a column having variable specific gravity, in which the beryl fragments float at a lower level than the quartz or feldspar. Benzene gradually evaporates and may have to be replenished for further tests.

A test for beryl, and other beryllium minerals that are attacked by ammonium fluoride, was developed by A.H. Debnam. It requires berillon reagent, understood to be available only from England. The mineral fragments are sintered with ammonium fluoride in a 25 millilitre silica crucible for 2 minutes, after which heat is increased to drive off excess fluoride. If only one fragment is being tested the following additions are made directly to the fragment in the crucible: 5 drops of 0.2 per cent normal nitric acid, 1 drop of 0.5 per cent berillon reagent (dissolved in water), and 2 per cent sodium hydroxide dropwise. If the mineral fragment contains beryllium a strong blue colour will develop in the solution after addition of about 8 to 10 drops of sodium hydroxide. However, if the colour remains red-violet the fragment does not contain beryllium. If several fragments are treated they are placed at least 1 centimetre apart on a filter paper. Onto each fragment 2 drops of 0.2 normal nitric acid, 1 drop 0.5 per cent berillon reagent, and 2 to 3 drops of 2 per cent sodium hydroxide are placed consecutively, so that the liquid soaks into the paper after each drop is placed. A strong blue coloration forms on the paper if beryllium is present, otherwise a dark red-violet colour appears.

Bismuth

If a little of a mineral containing much bismuth is heated on charcoal with three times as much soda ash, brittle globules of bismuth form and a yellow coating is formed on the charcoal; farther from the sample the coating is white.

Carbonates

Some carbonate minerals and rocks such as calcite and limestone effervesce when a drop of dilute hydrochloric acid is applied. Others, such as dolomite, effervesce only when powdered, and the powder may require heating in acid.

Cesium

The following test for pollucite, the main cesium mineral, was developed by the Manitoba Department of Mines and Natural Resources.

Equipment and reagents required

One 2-oz, clear *polyethylene* bottle with *polyethylene* dropper-insert and *polyethylene or polystyrene screw-cap.*

One 2-oz, brown polyethylene bottle, similarly equipped. (A clear bottle may be used if painted or otherwise covered to exclude light).

Reagent #1 (in clear bottle)

Concentrated hydrofluoric acid.

Reagent #2 (kept in brown bottle)

Prepare a saturated solution of 5 grams of reagent-grade potassium iodide (KI) by adding distilled water a drop at a time to the 5 grams of KI in a small beaker, until just dissolved. Add 1 gram of bismuth oxide (Bi_2O_3) and boil gently for a few minutes. Not all the Bi_2O_3 should dissolve. Add this mixture in small amounts to 25 millilitres glacial acetic acid contained in a small beaker, stirring to dissolve. Pour the solution into the brown polyethylene bottle and replace the dropper-insert and cap.

Procedure

By means of the dropping bottle, place a drop of reagent #1 on the rock or mineral, followed by a drop of reagent #2.

A bright red precipitate will form on pollucite. Quartz, feldspar, etc. show only amber stains easily distinguished from that on pollucite.

Note

Hydrofluoric acid is dangerous and must be handled with extreme care. Reagent #2 could be prepared by a pharmacist if apparatus for measuring were not available.

Chromium

Minerals containing chromium produce a yellow or red bead when heated with borax in an oxidizing flame, and a green bead with a reducing flame.

Cobalt

Dissolving in strong nitric acid forms a red solution that turns brown if ammonia is added in considerable quantity. The ammonia should be added carefully. The solution again becomes red after standing. Blue beads are produced if the mineral is heated with borax in either a reducing or an oxidizing flame.

Copper

Solutions in nitric or hydrochloric acid are blue or green, and become dark blue if considerable ammonia is added. Beads produced by fusion with borax in an oxidizing flame are green when hot and blue when cold.

Gold

An old saying that is generally true runs that, if there is any doubt about a mineral being gold, it isn't. Minerals with which it may be confused are yellow mica, identified by its flakiness and lightness, and sulphide minerals like pyrite, arsenopyrite, and chalcopyrite which emit sulphur fumes when heated and which are brittle and can be powdered, the powder being dark coloured. If a specimen contains much gold its heaviness will be apparent, and scratching will reveal its softness. If fragments can be detached or grains are obtained by panning, their fusibility and

malleability can easily be checked, as can their resistance to common acids and their ease of amalgamation with mercury.

Sulphide minerals may carry specks of gold too small to be seen even with a good hand lens. Such amounts are generally too small to be detected by blowpipe or other tests. Gold may be detected in larger amounts of crushed sulphide minerals or concentrates obtained by panning (for example, a quarter pound or more), by roasting to redness for four or five hours on a shovel or other container. The time may be reduced if one adds an equal amount of potassium chlorate. The residue is then pulverized, screened, and panned to concentrate any gold present.

Iron

So many minerals contain iron that chemical tests may not be helpful in identifying possible ore minerals, but the following are the principal simple tests. Iron minerals that are not normally magnetic may be made so by heating in a reducing flame, and cooling. This test is more delicate if a little sodium carbonate is added to the sample, which is heated on charcoal. If an iron mineral is dissolved in hydrochloric acid and boiled with a few drops of nitric acid, or dissolved in nitric acid, and if sufficient ammonia is added, a brownish red precipitate is formed.

Lead

Fragments of a mineral containing much lead will dissolve in dilute nitric acid, and a white precipitate will form if sulphuric or hydrochloric acid is added to that solution. Soft malleable globules resembling bird shot are formed if a mixture of one part of a lead mineral, one part powdered charcoal, and three parts sodium carbonate is placed in a cavity in a piece of charcoal and melted by a reducing flame; a sublimate is formed that is yellow near the sample and white farther away.

Lithium

Lithium minerals impart a characteristic crimson colour to a sufficiently hot flame. This is generally masked by a pervasive yellow colour due to sodium, but the latter can be filtered out by didymium glass, shade 1.7. Spectacles made of this glass are available from safety supply dealers. The heat required can be judged from the fusibility of the mineral. Cheap propane or automatic gasoline torches are effective on amblygonite, triphylite–lithiophilite, and most spodumene, but for petalite and dilute mixtures of fine-grained spodumene with rock-forming minerals, the greater heat of an acetylene torch is needed.

A staining test for amblygonite is as follows: The sample is heated almost to the boiling point with occasional agitation for 5 minutes in a solution of 5 grams of ammonium molybdate, 100 cc cold water, and 35 millilitres concentrated HNO_3. The solution is then decanted and the sample washed with water. A yellow coating of ammonium phosphomolybdate adheres to the surface of amblygonite, and is more evident after the specimen has cooled. The required solution probably could be prepared by a pharmacist if measuring apparatus were not available.

Magnesium

Fragments of some light-coloured magnesian minerals moistened with cobalt nitrate become pale pink when held in a flame.

Manganese

A bead made with sodium carbonate in an oxidizing flame is green, and one made with borax is purple, or black if much mineral is used. A solution of manganese in sodium metaperiodate is violet.

Mercury

If material containing mercury is heated the fumes can be identified by use of a special screen and an ultraviolet lamp. If a few grains of cinnabar are heated in a closed tube a black sublimate forms inside the tube, and is generally accompanied by small droplets of mercury. In making either test care should be taken to avoid breathing the fumes; testing in open air is recommended, especially for the fluorescence test, which may be performed with an open fire and a shovel.

Molybdenum

If thin flakes of molybdenite are placed in an open tube and heated highly, a sublimate will form in the tube. The sublimate is yellow when hot, but white when cold.

Nickel

Minerals containing much nickel form an apple-green solution when dissolved in nitric acid. More delicate tests can be made with dimethylglyoxime. A scarlet precipitate forms if a few drops of this reagent and considerable ammonia are added to a solution of nickel mineral in an acid. If iron is likely to be present tartaric acid should be added before the ammonia. If very little nickel is present red 'needles' form after the solution has cooled. Also, if a little nickel mineral is fused with borax in an oxidizing flame a bead is formed that is violet while hot and reddish brown when cold.

Niobium

A salt of phosphorous bead containing niobium, heated in an oxidizing flame, is pale yellow when hot and almost colourless when cold. In a reducing flame it is brown when hot and red-brown when cold. The chemical tests given in books seem too elaborate to describe here.

Silver

A test for silver can be made by dissolving a little of the mineral in concentrated nitric acid and diluting the solution with water. A white precipitate that darkens after exposure to light forms if a few drops of hydrochloric acid or a few grains of table salt are added to the solution.

Strontium

A fragment of a strontium mineral produces a crimson flame much like that of lithium if held in a flame after moistening with hydrochloric acid.

Sulphide Minerals

See notes on gold.

Tellurium

A telluride mineral will form a reddish violet solution if heated gently in concentrated sulphuric acid. The colour disappears and a greyish black precipitate is formed if water is added after the solution has cooled. A similar colour caused by manganese does not disappear after dilution with water.

Thorium

Potassium iodate forms a white precipitate in a strongly acid solution.

Tin

A piece of cassiterite acquires a dull grey coating of tin if placed in hydrochloric acid diluted with one part water, together with a few grains of zinc. A small dish or tray made of zinc or galvanized iron is useful for fine-grained samples, in which case zinc is not added and the coating appears on the metal. The film brightens when rubbed with cloth or soft paper.

Titanium

If a mineral carrying more than 3 per cent titanium is fused with borax or sodium carbonate and dissolved in hydrochloric acid, and the solution is boiled after addition of a little tin, a violet colour appears. A delicate test is to boil the mineral in a little concentrated sulphuric acid and an equal amount of water until the solution becomes clear. If it is then diluted with water, and hydrogen peroxide is added, the solution becomes yellow to amber in colour depending on the amount of titanium present.

Tungsten

A tungsten mineral forms a yellow residue when boiled in hydrochloric acid. If tin is added and boiling is continued a blue colour is formed, which changes later to brown. If a drop of water is placed on a piece of aluminum and a little finely powdered tungsten mineral is placed on it, together with a drop of hydrochloric acid, a blue colour is formed after standing. A

salt of phosphorous bead containing tungsten is colourless in an oxidizing flame, green when hot in a reducing flame and blue when cold.

Uranium

A fluorescence test that is useful for distinguishing minerals containing significant amounts of uranium from other radioacive minerals is made by fusing a little of the powdered mineral in a bead of sodium or lithium fluoride. If the sample contains an important amount of uranium the bead should fluoresce under an ultraviolet light. These fluorides are strong poisons. Yellow solutions are formed when a mineral containing much uranium is heated in common acids. A salt of phosphorous bead containing uranium is yellow while hot in an oxidizing flame and yellowish green when cold; in a reducing flame a green bead is formed.

Vanadium

If a vanadium mineral is dissolved in an acid (this generally requires heating in a concentrated acid) and a few drops of hydrogen peroxide are added after the solution has been diluted with water, the solution becomes reddish brown.

Zinc

If a large fragment of a zinc mineral is heated near the top of a blue flame, the flame is coloured by vivid bluish green streaks. Infusible, light coloured zinc minerals become green or blue when powdered, moistened with cobalt nitrate, and heated intensely. These tests are generally difficult to perform satisfactorily on specimens of sphalerite.

APPENDIX VII

Addresses

The following addresses which may be useful to some readers are those in use at the time this book was prepared. Although they change from time to time, inquiries would probably be forwarded if necessary.

Provincial Departments Related to Mining

Alberta: Department of Mines and Minerals, Edmonton, Alta.
British Columbia: Department of Mines and Petroleum Resources, Victoria, B.C.
Manitoba: Mines Branch, Department of Mines and Natural Resources, Winnipeg, Man.
New Brunswick: Department of Natural Resources, Fredericton, N.B.
Newfoundland: Mineral Resources Division, Department of Mines, Agriculture and Resources, St. John's, Nfld.
Nova Scotia: Department of Mines, Halifax, N.S.
Ontario: Department of Mines, Toronto, Ont.
Prince Edward Island: Deputy Provincial Secretary, Provincial Government Offices, Charlottetown, P.E.I.
Quebec: Mineral Resources Branch, Department of Natural Resources, Quebec, Que.
Saskatchewan: Department of Mineral Resources, Regina, Sask.

Northwest Territories and Yukon

Northern Economic Development Branch,
Department of Indian Affairs and Northern Development,
Ottawa, Ont.

Resident Geologist for Yukon,
Federal Building, Whitehorse, Y.T.
Resident Geologist for Northwest Territories,
Federal Building, Yellowknife, N.W.T.

Department of Energy, Mines and Resources

Geological publications, mineral identifications: The Director, Geological Survey of Canada, 601 Booth St., Ottawa, Ont.

Topographic Maps: The Director, Surveys and Mapping Branch, 615 Booth St., Ottawa, Ont.

Air Photographs: The Director, Surveys and Mapping Branch, 615 Booth St., Ottawa, Ont.
Attention: National Air Photo Library

Reviews on Metals and Minerals, etc:
The Director, Mineral Resources Branch,
Department of Energy, Mines and Resources, Ottawa, Ont.

Quebec Office: Department of Energy, Mines and Resources, 2136 Chemin Ste. Foy, Quebec 10, Que.

Branch Offices, Geological Survey of Canada

Institute of Sedimentary and Petroleum Geology: 3303–33 Street N.W., Calgary 44, Alta.

British Columbia Office: 6th Floor, Sun Bldg., 100 West Pender Street, Vancouver 3, B.C.

*Canadian Index to Geoscience Data**

Information Science Industries,
1755 Woodward Drive, Ottawa 5, Canada

* The *Canadian Index to Geoscience Data* is a computer-based coordinate index which identifies sources of data on the geology of Canada. The first edition (70-1) includes about 20,000 document titles, mainly from the Geological Survey of Canada, but it also includes titles from the Mineral Resources Branch; Quebec Department of Natural Resources; and Ontario Department of Energy and Resources Management.

Atomic Energy Control Board

The Secretary, Atomic Energy Control Board, P.O. Box 1046, Ottawa 4, Ont.

Entry to Canada

Canadian Immigration Division,
Department of Manpower and Immigration,
Ottawa, Ont.

Customs

Customs and Excise Division,
Department of National Revenue,
Ottawa, Ont.

Chambers of Mines

British Columbia and Yukon Chamber of Mines,
840 West Hastings Street, Vancouver, B.C.

Alberta and Northwest Chamber of Mines,
10009–105 Street, Edmonton, Alta.

Travel

Canadian Government Travel Bureau,
Department of Trade and Commerce, Ottawa, Ont.

Addresses for Some Periodicals Cited in References

Bulletin and Transactions, Canadian Inst. of Mining and Metallurgy,
906–1117 Ste. Catherine St. W.,
Montreal 2, Quebec.

Canadian Journal of Earth Sciences,
Administration, National Research Council of Canada, Ottawa 7, Ontario.

Canadian Mining Journal, Gardenvale, Quebec.

Economic Geology: Business Editor,
Economic Geology Publishing Company,
Box 26, Blacksburg, Virginia 24060, U.S.A.

Engineering and Mining Journal, 330 West 42nd Street, New York, N.Y. 10036, U.S.A.

Geophysics, P.O. Box 3098, Tulsa 18, Oklahoma 74101, U.S.A.

Mining Engineering, 345E 47th Street, New York, N.Y. 10017, U.S.A.

Mining in Canada, 1450 Don Mills Road, Don Mills, Ontario.

Northern Miner, 77 River Street, Toronto 2, Ontario.

Proceedings, Geological Association of Canada, Department of Earth Sciences, University of Waterloo, Waterloo, Ontario.

Western Miner, 1200 West Pender Street, Vancouver 1, British Columbia.

Laboratory Supplies

The names and addresses of some dealers in laboratory supplies are:

Canadian Laboratory Supplies, Limited,
8655 Delmeade, Montreal, Quebec.
80 Jutland, Toronto, Ontario.
535 Marjorie St., Winnipeg, Manitoba.
10989 124th St., Edmonton, Alberta.

Central Scientific Company of Canada, Limited,
2200 South Sheridan Way, Toronto, Ontario.
14920 Stony Plain Rd., Edmonton, Alberta.

Fisher Scientific Company Limited,
8505 Devonshire, Montreal, Quebec.
184 Railside, Toronto, Ontario.
14730 115A Ave., Edmonton, Alberta.

GLOSSARY

The following are brief definitions of selected terms and expressions used in this book. No attempt is made to define all terms or to provide full scientific or technical explanations, which are available in standard glossaries and textbooks, because inclusion of more than a few pages of definitions would be undersirable in a book of this kind. Definitions not included here may be found by using the index, terms generally being explained in the first page-reference cited. Names of rocks or minerals are not included because the more common ones are explained in Appendices IV and V.

Acid. A substance containing hydrogen which, when dissolved in water, separates and forms hydrogen ions. The term acidic is also applied to igneous rocks containing more than 66% silicon dioxide, but 'felsic', 'siliceous', or 'salic' is preferable.

Adit. A nearly horizontal opening large enough for the passage of men, excavated to test a mineral deposit or as the entry to a mine. Commonly called a tunnel by non-mining persons but, strictly, a tunnel is open at both ends.

Alkali. A name applied to a group of metals in Group I of the Periodic System of the Elements (*see* Appendix II), including lithium, sodium, and potassium.

Alluvial deposit. A deposit of sand, gravel or other material carried and deposited by a stream. Equivalent to 'stream-placer deposit'.

Analogous. Having both similarites and differences.

Analysis. The dividing (resolving) of a substance or concept into its simple elements.

Anomaly. A local abnormality to the uniformity of the geological composition or structure of a region, which becomes distinguishable by visual observation, geological mapping, or geophysical or geochemical surveys made over a larger area.

Anticline. An upward fold in layered rocks.

Amygdules. A mineral-filling of vessicles (gas holes) in volcanic rock.

Apex. The uppermost part of a mineral deposit, other than a flat-lying one.

Assay. Quantitative analysis by chemical or other techniques to determine the amounts of one or several metals present in a sample from a mineral deposit.

Attitude. A general term specifying the way a body of rock (stratum, dyke, etc.) lies. The term is also used to describe the way a fracture or fault lies. The attitude is determined by the strike *together with* the dip.

Axial plane. An imaginary plane transecting a fold through its crest and its axis.

Axis. An imaginary line passing through a crystal, fold, or mineral deposit about which it is symmetrical or nearly symmetrical.

Base. A compound that combines with an acid to form a salt; a substance that yields a grouping of oxygen and hydrogen when dissolved in water. The term basic is applied to igneous rocks that are low in silica and rich in minerals containing iron and magnesium, but 'mafic' or 'femic' is preferred.

Base-line. A line surveyed with special care, to which points or other lines are referred.

Base metal. Metals other than gold, silver, mercury, and the platinum group.

Batholith. A large mass of plutonic rock, having an area of at least 40 square miles, generally having sides sloping gently outward and enlarging downward.

Bedrock. Any solid rock exposed at the earth's surface or overlain by unconsolidated material.

Biogeochemistry. A branch of geochemistry dealing with biological materials and the results of biochemical research. Biogeochemical prospecting consists mainly of sampling and analyzing vegetation.

Blind deposit. A deposit that does not outcrop. The term 'blind' has been used both for deposits hidden by rock and for those hidden by overburden, but the former usage is most common and is so applied in this book.

Bonanza. A part of a mineral deposit that is especially rich, or a mine that is producing ore very profitably.

Boring. A general term for holes drilled in overburden or rock. The term is usually restricted to holes drilled for obtaining specimens or samples, rather than for blast-holes used in excavations or for wells drilled for oil or gas.

Breccia. A rock composed of angular fragments of minerals or rocks. Extensive bodies of rock may be composed of breccia, or narrow, irregular zones of breccia may be formed in pipes or along faults.

Breccia filling. Minerals filling openings between rock fragments in a breccia.

Carbonate. A salt of carbonic acid. Carbonate rocks include limestone, magnesian limestone, and dolomite.

Carbonatite. Intrusive carbonate rocks associated with alkaline igneous rocks, commonly in circular or ring-like forms. Uncertainty exists as to whether the carbonate minerals originated magmatically or by redistribution of carbonate in sedimentary strata.

Cavity filling. One or more minerals filling a small cavity in rock. Most such cavities are caused by solution of soluble rock, or are 'original' open spaces in volcanic rocks.

Chimney. See *pipe.*

Concentrator. A plant for concentrating ore by grinding and then separating the valuable minerals from the non-valuable material.

Concordant. Said of a mineral deposit lying parallel with the stratification or attitude of its enclosing host rock.

Contact. A surface or line bounding two rock units or a mineral deposit and its host rock.

Contact metamorphic. An expression applied to certain rocks and mineral deposits formed at high temperature around igneous contacts. See also *pyrometasomatic.*

Contact metamorphism. High-temperature alteration of the rocks adjacent to a body of plutonic rock at great depth, as a result of the heat and the gases given off.

Continental shelf. The gently sloping, shallowly submerged zone around the edge of the continents, extending from the shore to the point of an abrupt increase of slope to greater depths—about 100 fathoms or more.

Country rock. A general term for the normal rock or rocks surrounding a body of plutonic rock or a mineral deposit. In the latter case it is about equivalent to 'host rock'.

Daughter product or daughter element. An element formed as a result of the radioactive decay (see *radioactivity*) of another element.

Declination. The angle representing the difference between the direction in which the magnetic needle points (i.e., the position of magnetic north) and the position of true or geographical north.

Detrital. Grains of minerals or rocks resulting from the disintegration of rocks or mineral deposits.

Diamond drill. A machine for boring rock by means of a bit in which chips of diamonds are set. If core is desired for observation or sampling, the bit used is ring-shaped.

Differentiation. The separating of components of a magma.

Diffusion. Uniform spreading of a fluid or of ions through solutions, pores in rocks, or the spaces between the atoms of crystalline minerals.

Dip. The dip at which a stratum, fracture, fault, vein, etc., is inclined from the horizontal.

Dispersion halo. A zone surrounding a mineral deposit in which the concentration is intermediate between that of the deposit and that of the normal country rock.

Drift. Boulders, till, gravel, sand, or clay carried along by a glacier and deposited either directly from the ice when it melts or in the accompanying meltwater issuing from the glacier. Also used for a kind of tunnel.

Dyke. A tabular body (see *tabular*) of igneous rock filling a fracture in massive rock or cutting across the structure of layered rocks.

Dynamic metamorphism. Metamorphism produced exclusively or largely by rock deformation, principally folding and faulting. Extensive structural changes result from crushing and shearing of the affected rocks at low temperatures, and extensive recrystallization of the component rock materials occurs at higher temperatures.

Electro-magnetic. Concerned with the inter-relations of electricity and magnetism.

Eluvial placers. Detrital minerals concentrated near and downward from an outcrop by rainwater or gravity.

Empirical. Data obtained by experience or observation without necessarily indicating the fundamental causes.

Environment. A group term for all the surroundings of an object or organism.

Epigene. Group name for rocks formed at or near the surface of the earth (contrast *hypogene*, formed at depth).

Epigenetic deposit. A term applied to mineral deposits of later origin than the enclosing rocks.

Epithermal. A term applied to hydrothermal deposits formed at fairly low temperatures and shallow depths.

Erosion. A term including all the processes by which the rock materials of the earth's crust are loosened or dissolved and transported from place to place on the surface. It includes the processes of weathering, solution, corrosion, and transportation.

Esker. A narrow ridge of gravelly or sandy drift, deposited by a stream in an ice-walled valley or tunnel in stationary, or almost stationary, ice.

Evaporite. A mineral salt resulting from evaporation of seawater or saline lakes or ponds.

Even-textured. The texture of a rock in which the component mineral grains or crystals are about similar in size and shape.

Facies. With respect to rocks, a part of a rock group as distinguished from other parts by appearance or composition.

Fault. A break or shear in rocks, causing observable displacement of the two parts of the rock mass.

Felsic. A general term for fine-grained igneous rocks rich in feldspar.

Ferrous. Containing iron.

Fissure. Approximately equivalent to *fracture.*

Fissure system. A group of closely spaced fissures.

Fissure vein. A well-defined vein occupying a fissure.

Float. Loose fragments of rock, boulders, pebbles, and smaller particles that have been separated from a mineral deposit.

Flow. A tabular-shaped body of lava, which is magma that flowed slowly on the surface of the earth. Volcanic rocks consolidated from lava are also called flows, informally.

Fluid. In a general sense 'fluid' is a group name for both liquids and gases. It also has certain more specific chemical meanings.

Fluorescence. The emission of light by certain minerals when exposed to ultraviolet light.

Flux. A substance or mixture that promotes fusion, used in recovering metals in assaying or smelting.

Fold. A bend or undulation in layered rocks, resulting from compression, shearing, slipping, or sliding.

Foliation. A laminated structure resulting from the segregation of different minerals into parallel layers. Characteristic of schists, and commonly involving the parallel arrangement of platy minerals such as micas.

Fracture. A crack or other tabular opening in rocks, caused by compression, tension, or contraction.

Fuels, mineral. Coal, petroleum, and natural gas.

Fumarole. A vent on the side of or near a volcano.

Gal. The unit of the acceleration of gravity, being 1 centimetre per second per second.

Gamma. The most usual unit of magnetism for geophysical surveys.

Gamma ray. Electromagnetic radiation emitted by radioactive elements and minerals.

Gangue. Worthless minerals or rock in a mineral deposit or ore deposit. Includes worthless metalliferous minerals, but most gangue is non-metalliferous.

Gash vein. A short, narrow vein commonly tapering at the ends; so named in allusion to its appearance of filling a gash in rock.

Geiger counter. An instrument for detecting or measuring radioactivity by means of an ionization tube.

Geochemisry. The study of the abundances of elements and isotopes in the earth, and the distribution and migration of the individual elements in the various parts of the earth (the atmosphere, hydrosphere, crust, etc.) with the object of discovering principles governing such distribution and migration.

Geochemical prospecting. The search for mineral deposits, particularly metalliferous deposits, by analyzing rocks, stream silts, springs, soils, surface waters or organisms for abnormal concentrations of elements.

Geophysics. The science of the physics of the earth, including its atmosphere and hydrosphere.

Geophysical prospecting. Advanced prospecting based on measurements of physical properties of rocks and minerals.

Geosyncline. A regional, generally trough-like part of the earth's crust that sank slowly over a long time, thus permitting the accumulation of great thicknesses of sediments or lavas, or both.

Gossan. A rust-coloured upper part of some mineral deposits, largely composed of iron oxides resulting from the alteration of iron-bearing minerals near the earth's surface. Gossans are generally cellular or porous. A distinction is sometimes made between *gossans*, containing 20 per cent or more sulphides, and *cappings* containing less.

Gouge. Material resembling putty occupying a faulted fracture; formed of damp, powdered rock produced by movement along the fault.

Grade (of ore). The content of metal or mineral in ore expressed as a percentage or as pounds or troy ounces per ton.

Granitization. A term used in different connotations by different authors, but essentially referring to the formation of granitic and related plutonic rocks by alteration of pre-existing rocks.

Halo. A zone partly or entirely surrounding a mineral deposit.

Hertz. The unit of frequency equal to one cycle per second.

Horse. A large mass of unmineralized rock in a mineral deposit.

Host rock. In a general sense, the rock enclosing any mineral occurrence or deposit or other relatively small body such as a dyke or sill.

Hydrothermal. Hot fluid carrying dissolved elements, and deposits formed by such waters. Some geologists restrict the term to fluid derived from a magma, and others include heated groundwater.

Hypothesis. A provisional supposition serving as a basis for further investigation, which may prove or disprove it.

Igneous rock. A term formerly restricted to rocks that solidified or crystallized from a hot, molten or partly molten mass or magma that originated within the earth, and including both plutonic and volcanic rocks. Modern theories of granitization make the term less definitive than formerly.

Inclination. In geology: the dip of a bed, fault, vein, or other tabular body measured from the horizontal. In geophysics: the angle between any direction and the vertical.

Industrial deposit. A mineral deposit, rock, or unconsolidated deposit used in industry in its natural or partly processed state. Includes most non-metalliferous deposits, rocks used as building stone, crushed stone, etc., and commercial deposits of clay, sand, and gravel.

Industrial mineral. A mineral, generally non-metalliferous, that is used in industry in its natural or partly treated form, not for the extraction of an element.

Inference. The process of forming judgments or opinions on the basis of other judgments or on the evidence of observation. The two main types of inferences are *inductive*, the process of inferring some sort of order from observations, and *deductive*, the process of applying general truths or concepts to suitable instances.

Intrusive. A body of plutonic rock that was forced when molten or nearly molten, into other rock or rocks. In contrast, volcanic rocks are 'extrusive'.

Ion. An electrically charged atom or group of atoms; an atom or molecule considered electrically.

Isorad. Line joining points of equal radioactivity, drawn from Geiger counter or other radiometric data to form an isorad map.

Isotope. A group of two or more radioactive elements occupying the same position in the Periodic Table and having the same atomic number, and almost the same chemical properties, but differing in atomic weights.

Kame. A conical hill or short irregular ridge of gravel or sand deposited directly from a glacier.

Ladder-work (ladder vein). A series of short, parallel veins filling fractures, like the rungs of a ladder. They may cross a dyke or a particular stratum, or lie perpendicularly between two main parallel fractures or faults.

Laterite. Residual soils or mineral deposits formed of insoluble oxides of iron, aluminum, or other metals left after soluble material has been leached away. Especially characteristic of tropical climates.

Lava. Fluid rock such as that which issues from a volcano or a fissure in the earth's surface. The term is sometimes also used for volcanic rocks formed from such material.

Lens. A stratum, dyke, or vein whose sides taper out in lenticular fashion. The name is also used for a magnifying glass.

Lithology. The composition and texture of a rock, as opposed to its age or attitude.

Lode. A general term for metalliferous and some non-metalliferous deposits in solid, consolidated (hard rock) state. The term was formerly applied to a 'lead', 'ledge' or other tabular deposit but is now commonly used to cover all consolidated metalliferous deposits to distinguish them from unconsolidated deposits such as placers.

Mafic. A general term for dark rocks rich in magnesium and iron. *See* base.

Magma. Molten rock material including gases and vapours.

Magnetic susceptibility. A measure of the degree to which a substance is attracted to a magnet.

Magnetism, induced. Magnetism imparted to grains of certain minerals by the earth's magnetic field.

Magnetism, remanent. Magnetism retained permanently by minerals and rocks formed from them.

Marginal ore. Ore whose grade is about at the limit of economical mining.

Mesothermal. A term applied to those hydrothermal deposits formed at moderate temperatures and pressures.

Metallogenic. Related to the origin and distribution of metals in the earth's crust.

Metamorphic rock. Rock derived from pre-existing rocks by mineralogical, chemical, and structural alterations due to a response to pronounced changes of temperature, pressure, and chemical environment.

Metamorphism. The mineralogical and structural adjustment of solid rocks to physical or chemical conditions differing from those under which they were formed.

Metasomatism. A kind of metamorphism in which some material is added to pre-existing rock, and some other material is removed by solution.

Mill. The part of an ore-treating plant in which crushing and grinding takes place; also loosely applied to include the concentrating equipment.

Mine. An excavation for the production of ore, industrial minerals or rocks, or coal.

Mineral. A naturally occurring inorganic element or compound with a characteristic external structure as a result of a fixed internal arrangement of atoms or ions.

Mineral deposit. A fairly large concentration of minerals which are in general commercially valuable, but not necessarily so in the example being discussed or investigated.

Mineral lamp. A lamp emitting ultraviolet rays. Another name for 'ultraviolet' lamp.

Mineral occurrence. A small concentration of one or more minerals, or a naturally occurring example of a mineral having a quality interesting to a collector.

Mineralization. The process of mineralizing. Use of the term instead of 'mineralized rock', etc. is not recommended.

Model. An object or formula used to aid in understanding or explaining a concept or a set of data.

Molecular structure. The arrangement of atoms, ions, or molecules in an element or compound.

Moraine. An accumulation of earth, stones, etc., carried and finally deposited by a glacier.

Native. A term applied to a mineral occurring as an element alone, instead of in combination with one or more other elements. Gold is generally in the native state; silver, copper, and some other elements are sometimes found as native minerals.

Noble. Metals that do not oxidize when heated in air or water: gold, silver, mercury, and the platinum group.

Non-ferrous. Metals other than iron.

Non-metallic. Minerals without metallic lustre. In statistical contexts equivalent to 'non-metalliferous'.

Non-metalliferous. Minerals or deposits that do not contain metals.

Oolite. A roughly spherical mineral body, resembling fish roe, and usually calcareous.

Ore. A mixture of one or more minerals forming a deposit that can be mined at present at profit to the operator or to the benefit of a country; generally applied to deposits containing one or more metals but also applied to some kinds of non-metalliferous deposits.

Ore deposit. A mineral deposit that can be mined at present at profit to the operator or to the benefit of a country.

Ore mineral. A valuable mineral in an ore. Also used to describe such minerals whether or not the particular example constitutes ore.

Ore shoot. A large and unusually rich aggregation of mineral constituting ore in a mineral deposit otherwise below ore grade.

Orogen. A regional geological unit that was involved in orogeny.

Orogeny. Regional structural disturbances such as folding, faulting, and metamorphism associated with the formation of mountains.

Outcrop. Rock or part of a mineral deposit exposed at the surface.

Overburden. A general term for unconsolidated sand, gravel, clay, soil, etc., overlying bedrock.

Overburdened deposit. A mineral deposit that reaches the surface of bedrock but is hidden by overburden.

Parameter. A constant or a variable in a mathematical expression, distinguishing various specific cases.

Pathfinder elements. Certain elements commonly accompanying a particular metal of value, and which can be detected more readily than the valuable metal itself. Geochemical indicators.

Pegmatite. Coarsely crystalline rock of plutonic or replacement origin, generally forming dykes, sills, or small irregular masses.

Permafrost. Overburden that is frozen permanently, in both summer and winter.

Photogeology. The study, interpretation, and illustration of geological information shown on photographs, usually air photographs.

Pipe. A mineral deposit having two relatively short dimensions and one relatively long dimension.

Placer. A deposit of heavy or resistant minerals in sand or gravel, or a consolidated deposit of that kind interlayered in rock such as sandstone, quartzite, or conglomerate. When the word is used alone it usually refers to an unconsolidated deposit, otherwise it is usually called a consolidated placer or consolidated placer deposit.

Platform. A region in which a 'basement' of older rocks is overlain by younger, relatively flat-lying strata.

Plunge. The angle at which the axes of certain folds slope. The vertical angle between a horizontal plane and the line of maximum elongation of a mineral deposit.

Plutonic. A general term used originally for igneous rocks crystallized at depth, as opposed to volcanic rocks; now also used by some geologists to include granitized rocks, large masses of metamorphosed rocks, and granitic complexes.

Porphyry. Igneous rock in which relatively large crystals, called phenocrysts, are contained in a fine-grained groundmass.

Porphyry–copper deposit. A type of disseminated copper deposit originally restricted to those in porphyries but now largely a mining term for any low-grade disseminated copper deposits.

Potential. In general usages, having possibilities but not actualities. In electrical contexts, the work required at a given point to bring a unit of positive electricity from an infinite distance to that point under given electrical conditions.

Precious metals. Gold and silver only.

Precipitate. The solid produced when a chemical reaction produces an insoluble compound.

Primary. A term which, in its traditional sense, meant a mineral or mineral deposit in its original, unaltered state. In some contexts it is now used to include a mineral or deposit that may have been recycled from a pre-existing mineral or deposit, but which is quite different from a secondary (or supergene) mineral or deposit.

Prospect. A mineral deposit that has some prospect of being of mineable size and mineral content.

Protore. Unworkable, primary mineralized material from which supergene-enrichment ores have been formed. The term is also used in different contexts for substantial amounts of material too low in grade for present mining but which may become ore if conditions are changed; the terms sub-marginal ore or potential ore are less ambiguous.

Pyrometasomatic. Deposits formed by metasomatic changes at or near plutonic contacts. The term is a little broader than 'contact-metamorphic deposit'.

Radioactivity. The property shown by some elements of changing into other elements by the emission of charged particles (*alpha* particles which are positively charged helium atoms or *beta* particles which are electrons) or *gamma* rays from their nucleii.

Radioactivity detector. An instrument for detecting or measuring radioactivity.

Rake (pitch). The inclination of a tabular deposit or ore shoot

measured in its plane. Thus a deposit may dip in one direction and plunge in another.

Regional metamorphism. A general expression for metamorphism that affected rocks over extensive areas.

Replacement. A simultaneous process by which one mineral is dissolved and removed while another is deposited in its place.

Resistivity. The measure of the resistance offered by a substance to the flow of a specific electrical current.

Rock. Strictly, any natural accumulation of one or more minerals, but usually restricted to hard, solid accumulations of minerals.

Scintillation counter. A radioactivity detector in which rays cause scintillations (flashes) of light when passing through one of certain crystalline compounds, the amount of light being measured by a photo-electric cell.

Secondary. A general term applied to minerals formed by the alteration of pre-existing minerals. Also applied to certain mineral deposits or parts of deposits containing secondary minerals. In some contexts synonymous with 'supergene'.

Sedimentary deposit. A mineral deposit formed by sedimentary processes at the same time as its enclosing strata.

Sedimentary rock. Rock formed by the deposition of sediments under water or on dry land.

Seismic. Effects of earthquakes or man-made explosions or hammer-blows.

Shaft. A narrow downward excavation in overburden or rock.

Shear zone. A zone of sheared rock consisting of many closely spaced, approximately parallel fractures along which movement has occurred.

Shear-zone deposit. A mineral deposit formed in a shear zone by replacement or by filling fractures.

Sheeted vein. A vein composed of several, approximately parallel, narrow veins separated by rock.

Shield. A geologically ancient, regional platform part of the earth's crust that has been relatively stable for a long time.

Sill. A tabular body of plutonic rock intruded parallel with the layering of layered rocks. Some writers restrict the term to horizontal bodies, but in this book the term is used for horizontal or sloping bodies.

Slickenside. A polished or scratched rock surface caused by friction along a fault plane.

Smelter. A plant for the extraction of metals by melting concentrated or 'run-of-mine' ore.

Spatial relations. Relations with respect to distance or position. In connection with mineral deposits the expression is used to refer to their position with respect to a geological body, such as a stock or batholith, without implying that the deposit was derived from that body.

Spectrometer. An instrument for measuring a particular kind of spectra.

Spectrum. A dispersed and blending beam of radiant energy, such as light or gamma rays. The term is also used figuratively for a transitional blending of ideas.

Stock. A body of plutonic rock having an area of less than 40 square miles. Such a body may be separate or may be an upper part of a batholith.

Stockwork. A network of many small, closely spaced veins separated by fractured rock.

Strata-bound deposit. A concordant or transcurrent mineral deposit occurring in stratified sedimentary, volcanic, or metamorphic rocks, not necessarily formed at the same time as the strata.

Stratiform. Composed of layers; having the form or appearance of strata. In connection with mineral deposits, used as a general term to describe a concordant deposit interlayered with strata but not necessarily formed at the same time as the strata.

Strike. The course, direction or bearing of an inclined stratum, fracture, fault, vein, etc., measured in a horizontal plane.

Stringer. A small narrow vein occurring independently or extending from a larger vein.

Stripping. The removal of moss, overburden, or rock in sheet-like sections rather than in trenches.

Sulphate. A compound of an element with sulphur and oxygen.

Sulphide. A compound of sulphur with another element.

Supergene. A term applied to minerals or parts of mineral deposits formed by weathering, groundwater, or bacteria, as opposed to 'hypogene'.

Syncline. An inward or downward fold in layered rocks. Opposite to anticline.

Tabular. A term applied to a body, such as a vein or stratum, that is relatively thin in one direction as compared with the other two directions.

Tectonic. The form, pattern, and evolution of large structural units of the earth's crust. Partly equivalent to 'orogenic'.

Tenor. The content of metal in a deposit, expressed as a percentage or as pounds or ounces per ton, etc. A more definitive term than 'grade'.

Theory. A concept or mental scheme of something, or a systematic statement of scientific rules and principles. The term is loosely used in the same sense as hypothesis, but is more properly used for a hypothesis that has been confirmed by observation or experiment.

Transcurrent (transgressive). Said of a mineral deposit that crosses the stratification or attitude of its enclosing host rock.

Traversing. Prospecting or surveying by systematic lines along which positions are determined.

Trenching. Long, narrow, and fairly shallow excavations in overburden or rock.

Unconformity. A 'break' between bodies of rocks, caused by a period of erosion or by a temporary lack of deposition.

Unconsolidated deposits. Material in loose form, not converted to solid rock. Includes weathering products in place, placers, and deposits of clay, sand, gravel, etc.

Variable. A quantity subject to continuous increase or decrease. A variable used in a model or formula is a quantity representing a particular case.

Vein. A mineral deposit whose width is much less than its other two dimensions. Most veins lie in fissures, which may have been open at the time the vein was formed, or may have been forced apart as the vein was deposited. Other veins replace rock-forming minerals.

Veinlet. A small vein.

Vesicles. Openings in lava, caused by expanding gas.

Vug. An unfilled cavity in a mineral deposit, caused by solution or lack of deposition.

Weathering. Physical or chemical changes at or near the surface by the effect of atmospheric agencies such as rain, freezing, wind, or heat from the sun.

Zoning (zonation). Zonal arrangements of minerals in a deposit or of different kinds of deposits in an area, caused by differences in the temperature or pressure of formation of minerals, or by the distribution of different kinds of host rocks.

Zwischengebirge. A large structural unit composed of less deformed rocks lying between two large, more deformed mountainous belts.

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