GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

MEMOIR 374

GEOLOGY OF THE PORT RADIUM MAP-AREA, DISTRICT OF MACKENZIE

G. Mursky

Price, $ 2.50

Ottawa
Canada
1973

GEOLOGY OF THE PORT RADIUM MAP-AREA, DISTRICT OF MACKENZIE

1,300—1972—6253-4

Technical Editor
R. G. BLACKADAR

Critical Reader
J. C. MCGLYNN

Editor
DORCAS CUTHBERT

Text printed on Georgian Offset smooth (brilliant white)

Set in Times Roman with News Gothic condensed captions by
CANADIAN GOVERNMENT PRINTING BUREAU

Artwork by CARTOGRAPHIC UNIT, GSC

GEOLOGICAL SURVEY
OF CANADA

MEMOIR 374

GEOLOGY OF THE PORT RADIUM MAP-AREA, DISTRICT OF MACKENZIE

By

G. Mursky

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
CANADA

Available by mail from Information Canada, Ottawa,
from Geological Survey of Canada, 601 Booth St., Ottawa,
and at the following Information Canada bookshops:

HALIFAX
1687 Barrington Street

MONTREAL
640 St. Catherine Street West

OTTAWA
171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

VANCOUVER
800 Granville Street

or through your bookseller

A deposit copy of this publication is also available
for reference in public libraries across Canada

Price: $2.50 Catalogue No. M46-374

Price subject to change without notice

Information Canada
Ottawa, 1973

PREFACE

An objective of the studies carried out by the Geological Survey is to estimate the potential abundances and probable distribution of the mineral and fuel resources available to Canada.

The Port Radium district has, since 1900, attracted attention. In 1930, pitchblende and silver deposits were discovered and during World War II these assumed great importance.

In this report the author brings together most of the results of the geological work that has been conducted by government and private agencies during the past forty years. Much of this information has until now been unpublished.

Not only is the report valuable as a compendium of information on the geology of the Port Radium area, but it also assists in establishing the settings and geological characteristics that define such deposits and thus establish criteria that will assist in the search for similar mineral deposits.

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

OTTAWA, February 14, 1972

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

Illustrations

GEOLOGY OF THE PORT RADIUM MAP-AREA, DISTRICT OF MACKENZIE

Abstract

All rocks in the map-area are of Precambrian age. The oldest stratified units belong to the Echo Bay Group which consists of sedimentary and volcanic rocks. Lying above the Echo Bay Group is a succession of younger sedimentary rocks which belongs to the Cameron Bay Group. Both groups are intruded by stock- and sill-like bodies of feldspar–hornblende porphyry and by more extensive granitic bodies of batholithic dimensions. Diabase dykes and sheets, which often occupy faults and shear zones, are the youngest rocks in the area.

Shear zones and faults comprise an important structural feature of the district. A number contain quartz and carbonates as vein material and have occurrences of uranium, silver, and copper. Most of the known occurrences are small and show no economic promise.

Résumé

Toutes les roches de la région datent du Précambrien. Les couches les plus anciennes appartiennent au groupe de la baie Echo; elles sont volcaniques et sédimentaires. Ces couches sont recouvertes par une suite sédimentaire plus jeune qui fait partie du groupe de Cameron Bay. Les deux groupes présentent des intrusions de porphyre à feldspath et hornblende ressemblant à des stocks ou des filons-couches et des intrusions granitiques ayant les proportions de batholites. Les dykes et lames de diabase comblant les failles et zones de cisaillement sont les roches les plus récentes de la région.

Les zones de cisaillement et failles forment un élément important de la structure géologique. Certaines d'entre elles renferment du quartz et des roches carbonatées sous forme de veines ainsi que des indices d'uranium, de cuivre et d'argent. La plupart des venues minérales connues sont petites et offrent peu d'intérêt quant à l'exploitation.

Chapter I

INTRODUCTION

Location and Accessibility

Port Radium map-area, which covers about 300 square miles, lies along the eastern shore of Great Bear Lake in the central District of Mackenzie, Northwest Territories. It is bounded by latitudes 66°00′ and 66°15′ N and longitudes 117°30′ and 118°00′W. Port Radium is the largest settlement in the area. Coppermine (150 miles), Fort Franklin (166 miles), Colville Lake (230 miles), Fort Norman (233 miles), Norman Wells (260 miles), and Yellowknife (270 miles) are some of the other permanent communities. The mining camp at the Terra mine (34 miles) on Camsell River is now (1970) into its second winter and a trailer camp on the Norex property (35 miles) has been sporadically occupied.

The most practical access into the area is by aircraft. Large, wheel-equipped aircraft can land at Sawmill Bay airstrip located some 40 miles away on the south shore of Great Bear Lake and small planes, equipped with floats during the summer and skis during the winter, can land on the numerous lakes within the map-area. Smaller aircraft can also land on a dirt airstrip beside Glacier Lake when the surface has not been softened by rain and is otherwise suitable.

A winter truck road was first established from Rae to Great Bear Lake, via Marian Lake and Camsell River, by Byers' Transport during the winter of 1961–62. The road has been used since the winter of 1964–65 for trucking heavy freight to Echo Bay Mines Ltd. and trucking out copper concentrate and part of the silver concentrate. During the past few winters mill equipment, fuel, and other supplies have been trucked into Terra mine and other properties on Camsell River. Heavy freight can be shipped from Fort McMurray, 1,400 miles away, down the Slave and Mackenzie River system, up Great Bear River and across Great Bear Lake. Northern Transportation Co. operates the waterway transportation system from about July 10 to October 20 and the entire trip normally takes about five weeks.

Transportation in the region is dependent on the break-up period which extends from late May to early July and on the freeze-up period which lasts from early October to early December. Smaller lakes generally freeze and thaw earlier than larger lakes.

Physiography and Climate

The map-area displays physiographic features characteristic of the Canadian Shield. From the air it appears nearly featureless but, when seen in detail, it is rather rugged. The entire area gives a picture of a dissected, rolling plateau. The topography

MS. received February 14, 1972.

is largely controlled by faulting and by the resistance of rock types. Relief is greatest along the shores of Great Bear Lake with a maximum elevation of about 1,500 feet above the level of the lake. Along these shores the rocks form rugged, scarp-faced hills fringed with talus slopes and numerous fiord-like bays. Vertical cliffs, up to several hundred feet high, are common. This rugged, deeply dissected terrain extends about 15 miles east from Great Bear Lake where the topography becomes more subdued with rolling hills seldom more than 300 feet high. Generally, deeply dissected rugged terrain is underlain by sedimentary and volcanic rocks whereas intrusive porphyritic and granitic rocks give rise to hummocky rounded topography. Numerous lakes follow the strike of softer beds or fill depressions scoured by glaciers. These lakes occur as much as 1,000 feet above the level of Great Bear Lake. About 50 per cent of the map-area is outcrop and the remainder is covered by drift or talus or occupied by lakes. Most of the faults and shear zones, which constitute the main loci of ore deposits, are filled with drift and detrital material. This seriously hinders prospecting by conventional field methods.

Glaciers have stripped the soil cover from the bedrock thus providing rounded outcrops and a high percentage of bedrock exposure. They have also modified the original topography by deepening the valleys, disrupting drainage, and depositing glacial material in the form of morainal ridges, eskers, and erratic boulders. Frost thrusting is a common and striking physiographic feature and is especially evident in low areas and where the rocks are strongly jointed.

The climate of Port Radium map-area is subarctic with long cold winters and temperatures as low as —78° F but averaging about —20° F during January and February. The summers are short but pleasant with an average temperature of about 45°F during the period June to September and temperatures as high as 80°F during July and August. For two weeks, between June 15 and 30, the sun does not disappear below the horizon and daylight is continuous from about May 25 to August 1. Annual precipitation is generally less than 10 inches, mostly in the form of rainstorms during late August and throughout September. This period is also marked by storms and low clouds and in late September the smaller lakes freeze over. The average field season is from June 15 to September 15 although field work could begin early in May before spring break-up when the rocks are sufficiently exposed and the absence of flies provides pleasant working conditions.

In the map-area the ground is permanently frozen to depths of 200 to 300 feet but this permafrost blanket is not present below larger lakes.

Previous Work and History

Great Bear Lake and parts of Port Radium map-area were first visited by J. M. Bell in 1900 who, during a hasty reconnaissance of the shores of Great Bear Lake, had observed copper and cobalt bloom on LaBine Point (Bell, 1901, p. 102). No significant work was done between 1900 and 1930, but in 1930 Gilbert LaBine and E. C. St. Paul, spurred on by Bell's observation, discovered pitchblende and silver deposits at LaBine Point. This discovery led to intensive prospecting in the district during 1931 when some 3,000 claims were staked.

The year 1931 also marked the first shipment of pitchblende concentrates although mill operations did not begin until 1933. Full-scale production from the property was not attained until 1934 by Eldorado Gold Mines, Limited. This name was changed to Eldorado Mining and Refining, Limited and later to Eldorado Nuclear Limited. A plant for radium extraction built in Port Hope, Ontario began treating pitchblende in 1934. In 1933, a townsite which had been established at Cameron Bay became the focal point of all mining activity and exploration in the area. Later, this townsite was abandoned and Port Radium became the centre of activities.

Following Bell's work, D. F. Kidd and A. W. Jolliffe of the Geological Survey of Canada spent the field seasons of 1931 and 1932 in the Great Bear Lake region. This work was summarized by Kidd (1932) in four reports. During the same general period geologists working for private companies, notably Robinson (1933), Riley (1935), and Furnival (1939), mapped small areas in the Echo Bay area. During subsequent years, until 1944, field work in the area was largely discontinued except for geological mapping at Port Radium mine by Richard Murphy and A. W. Estey during the late thirties and early forties. Owing to conditions imposed by the war and an oversupply of radium in the world markets the Port Radium mine suspended operations in 1940 only to reopen in 1942.

After the reopening of the Port Radium mine in 1942 and two years of relative inactivity the shares of the company were, for reasons of security, purchased by the Canadian Government and in 1945 Eldorado Mining and Refining (1944) Limited became a Crown company. This changeover and the increased demand for radioactive products led to detailed mapping in the Port Radium map-area by the Geological Survey of Canada, principally by Jolliffe and Bateman (1944), Thurber (1946), Fortier (1948), and Feniak (1947). Bibliographies compiled by Griffith (1956) and Ridge (1958) list additional relevant studies and publications for this area and work by Lord (1952) provides an account on geology south of the map-area. Geological coverage east and north of the map-area consists of a map by Fraser (1960) at a scale of 8 miles=1 inch. During the years the Port Radium mine operated much valuable geological information has been compiled by Eldorado geologists. This includes studies of Campbell (1955), Mursky (1963), and Jory (1964), as well as less formal contributions, in the form of company reports and maps, by M. S. Lougheed, K. Donald, M. Trigg, G. Woollett, and J. A. Allan.

Acknowledgments

The information and data summarized in this report came from many sources and in different forms. The writer has drawn freely from all the available published and unpublished data. Special reports and maps, by the officers of the Geological Survey of Canada, supplied the essentials of the information. Reports and maps by Jolliffe and Bateman (1944), Thurber (1946), Fortier (1948), and Feniak (1947) were especially useful. Works by Robinson (1933), Kidd (1932), Riley (1935), and Furnival (1939) added significantly to the available information and a thesis by Campbell (1955) provided excellent details on the geology of the LaBine Point area. The writer had free access to all available exploration and Port Radium mine area records of Eldorado Nuclear Limited. These records proved invaluable for the preparation of this report. Without the sources of information cited above, the contributions of individuals listed under the section Previous Work and History, and those credited throughout the text and listed in the References, it would have been impossible to compile a meaningful report. Figure 5 (*in pocket*), an airborne geophysical map, was compiled from geophysical maps prepared for Eldorado Nuclear Limited from data derived from a geophysical survey conducted by Hunting Survey Corporation Limited.

Chapter II

GENERAL GEOLOGY

All rocks in the Port Radium map-area are of Precambrian age. The oldest stratified units belong to the Echo Bay Group which consists of a lower 4,500 feet of dominantly sedimentary strata and an upper 5,000-foot sequence composed mainly of andesitic flows. Lying above the Echo Bay Group with apparent unconformity is a succession of younger conglomerates and arkoses which belong to the Cameron Bay Group. Both groups are intruded by stock- and sill-like masses of feldspar–hornblende porphyry and by more extensive granitic bodies of batholithic dimensions. Diabase dykes and sheets, which occupy faults and shear zones, are the youngest rocks in the area.

The lower unit of the Echo Bay Group consists mainly of fine-grained siliceous argillites, banded and massive cherts and, near the top, thin porphyritic andesite flows, tuff, conglomerate, and greywacke. This predominantly sedimentary succession is overlain by thick, distinctly coarser and porphyritic andesite flows and minor tuffaceous rocks of the upper unit. The base of the Echo Bay Group is truncated by granite at Dowell Point and LaBine Point.

The Cameron Bay Group is characterized by coarse cobble- and pebble-conglomerates and arkose. Both rock types, in contrast to conglomerates from the Echo Bay Group, contain a highly ferruginous maroon matrix and are poorly consolidated. Due to gentle dips the rocks of the Cameron Bay Group form flat-topped hills and terraces whereas the steeper dips of the Echo Bay Group account for more rugged topography.

Feldspar–hornblende porphyries are among the oldest intrusive rocks in the area. In composition they vary between rhyolite and andesite, are typically porphyritic, and display a variety of colours. They intrude rocks of the Echo Bay Group extensively and account for recrystallization and metasomatism of the older rocks.

Granitic rocks of several ages and composition intrude all rock types mentioned above. Pyritization of country rock and the extensive development of gossan zones are probably related to these intrusions. Locally, they are also responsible for intricate folding of older rocks and for the recrystallization of fine-grained volcanics.

Faults and shear zones constitute a major structural feature in the district. Most have steep dips and strike northeasterly and in places are occupied by diabase dykes and nearly contemporaneous quartz stockworks. They also served as channelways for later pitchblende and silver ore solutions.

Echo Bay Group

The name Echo Bay Group was first applied by Robinson (1933) to a sequence of sedimentary and volcanic rocks exposed along the shores of Echo Bay. This name was adopted by all workers engaged in mapping throughout the Echo Bay map-area except Parsons (1948) who assigned lithologically similar rocks in the region to the south of the Snare Group. Parsons also suggested that the two groups are correlative and should be placed in the same age division. Because of two broad lithological differences in the Echo Bay Group the practice has been to subdivide the rocks into lower and upper units. Thurber (1946) is the only one who suggested a threefold subdivision based on his work in the Glacier Bay–Cameron Bay area. Because only the lower and the upper units are distinct over most of the Port Radium map-area, the twofold subdivision has persisted and is adopted in this report. The lower unit consists predominantly of sedimentary strata whereas the upper unit is composed mainly of volcanic flows.

It is difficult to determine the total thickness of the Echo Bay Group, mainly because the base of the section has not been seen. The lowermost members of the group, wherever observed, are cut by a younger granite making a thickness estimate impossible. Even though local pinching of individual rock units contributes to the variations in thickness, 9,500 feet appears to be a reasonable estimate for the aggregate thickness of the exposed section.

Lower Unit

Best exposures of the rocks from the lower unit are located on Dowdell Peninsula between Hoy Bay and Mile Lake and in the area bounded by LaBine Point, Cross Fault Lake, Wop Lake, and Great Bear Lake. Less extensive and intermittent exposures are found at the end of Glacier Bay and along the eastern tip of Mystery Island and the peninsula to the east of it. Furnival (1939) reported a small exposure of similar rocks just west of the east arm of Echo Bay and Feniak (1952) described an assemblage on Stevens Island which lithologically and structurally resembles the members of the lower unit, although he has assigned this assemblage to the Cameron Bay Group.

The major part of the lower unit is made up of alternating bands of green, grey and maroon cherts, cherty argillites, quartzites, tuff and, near the base of the exposed sections, two calcareous beds about 30 and 20 feet wide. Overlying this essentially sedimentary sequence is a section composed of a mixture of thin volcanic flows and sediments. Although the order is not discernible in every exposure, the general succession consists of alternating beds of andesitic flows, argillites, tuffs, arkose, pebble-conglomerate, breccia, and brecciated cherty argillites. Intruding the rocks of the lower unit, in a generally conformable manner, are dacitic sill-like bodies of feldspar–hornblende porphyry.

Cherts and cherty argillites as well as the calcareous beds near the base of the section are, for the most part, very fine grained, channeled or ripple-marked and without any grain gradations. In contrast, similar sedimentary members higher up in the section are not ripple-marked or channeled but show graded bedding. Structurally, the latter are relatively undeformed and dip less than 30 degrees. Most commonly they are pink or reddish brown with microcryptocrystalline texture. Quartzites and tuffs are more heterogeneous and texturally exhibit greater variation from one area to another. Cherty rocks are mainly massive but near the base, immediately above the calcareous units, the cherty argillites are finely banded with beds ranging in thickness from a few millimetres to several dozen feet. Where lime content is fairly high, cavernous structures may be present. Along their borders with intrusive feldspar–hornblende porphyries, cherty rocks have been metamorphosed and metasomatized to assemblages of hornblende, diopside, magnetite, albite, biotite, garnet, scapolite, and epidote (noted in order of abundance).

The conglomerates contain pebbles and occasionally cobbles of all rock types from the basal units of the lower unit and are well consolidated with a cherty matrix; these features distinguish them from the Cameron Bay Group conglomerates.

A series of thin flows comprise the upper part of the lower unit. Individual flows are not more than 150 feet thick and most are less than 100 feet. Some are thin and of limited extent. Not uncommonly one flow may pinch out and another, from a different stratigraphic horizon, appears. This and the identical appearance of many flows make their recognition extremely difficult. The flows are mostly siliceous andesites and trachytes. There is some indication that the flows closer to the top of the section are more basic than those lower down.

The andesites and trachytes are generally dense and massive in lower members and slightly porphyritic near the top where they contain phenocrysts of hornblende and feldspars in varying proportions. The phenocrysts are typically about 1 to 2 mm across but may reach 0.6 cm. At some horizons rounded plagioclase phenocrysts prevail and impart a spotted appearance to the rock on weathered surfaces. Hornblende phenocrysts are often altered to chlorite and less commonly to biotite whereas feldspar phenocrysts are generally dull earthy grey or white due to saussuritization and kaolinization.

Some flows are capped by fragmental tops. The fragments, measuring more than 6 inches, are similar in composition to the matrix and thus are difficult to detect. At least some of the so-called fragments may be pillows. Vesicles, which are often filled with quartz or chlorite, are scarce and are confined to the flows near the top of the lower unit. Intermixed with the andesitic and trachytic flows are a few beds of grey breccia and tuff and thin-bedded argillitic sediments. The argillites are locally ripple-marked and are the youngest beds of the lower unit on Dowdell Peninsula.

Upper Unit

Rocks of the upper unit of the Echo Bay Group are widely distributed throughout the Port Radium district. Nearly continuous, gently dipping exposures are found along the shores of Great Bear Lake stretching inland for about 5 miles. They conformably overlie the rocks of the lower unit and are about 5,000 feet thick. The best, and most nearly continuous stratigraphic section, is exposed on Dowdell Peninsula between Hoy Bay and Gossan Island. In other areas the sections are not as complete.

The upper unit consists predominantly of andesitic flows and minor interbedded quartzite, argillite, tuff, and greywacke. The flows, which are markedly coarser grained than those in the lower unit, form an aggregate thickness of about 4,500 feet whereas the sediments comprise about 500 feet. The sediments are generally similar to comparable rock types encountered in the lower unit except for their slightly coarser textures and darker colours.

Andesitic flows, which individually are up to 200 feet thick, are predominantly porphyritic with phenocrysts of andesine or oligoclase and hornblende. The phenocrysts measure up to 1 inch. The groundmass is felsic, microcrystalline, dark grey or purple, and trachytic consisting of tiny laths of feldspars, chlorite, sericite, carbonate, and epidote. The main parts of flows are massive and do not exhibit any primary structures except for occasional alignment of phenocrysts parallel to the bedding planes. Near the top, however, most flows are either amygdaloidal or vesicular with distinct alignment of phenocrysts. Occasionally these parts are fragmented to the extent that they may be called flow breccias. These flow breccias are more abundant in the flows at the top of the stratigraphic section than near the bottom. Feniak (1947) provided a set of criteria for distinguishing the tops of andesitic flows. These criteria are tabulated in Table I.

TABLE I *Criteria for the identification of main parts and tops of flows in the upper unit of the Echo Bay Group volcanics (after Feniak, 1947)*

Criteria for the identification of top parts of flows	Criteria for the identification of main parts of flows
1. Dusty red colour common on weathered surfaces	Iron stain largely confined to joints and fractures
2. Feldspar phenocrysts are white or pink	Feldspar phenocrysts are grey or grey-green
3. Feldspar phenocrysts commonly weather in relief	Feldspar phenocrysts commonly weather out, forming pits
4. Commonly amygdaloidal, amygdules are oriented	Amygdules are absent, or scarce and irregular
5. Flow breccias common	No breccias observed
6. Groundmass commonly a rusty grey	Groundmass dark grey, maroon, or greenish grey
7. No joint pattern present	Sheet jointing and vertical jointing common
8. Noticeably altered, mineralized, or recrystallized near intrusive rocks	Only slightly affected by nearby intrusions
9. Irregular jasperoid and milky quartz blebs locally common	Contain quartz veins but no irregular blebs
10. Clastic dykes present	Contain no clastic dykes
11. Overlain by tuffs, sediments, or massive flow; underlain by massive flow	Overlain by flow breccia or amygdaloidal flow; underlain by tuffs, sediments, breccias, or amygdaloids
12. Generally have heterogeneous appearance	Homogeneous over large areas

Plagioclase phenocrysts are as large in thin as in thick flows and in all instances show evidence of alteration to saussurite. Hornblende phenocrysts are altered to chlorite and less commonly to biotite. Where alteration of plagioclase phenocrysts is intense they are altered to albite, calcite, and quartz. Generally, the phenocrysts from the tops of the flows are less altered and thus are more resistant to weathering. As a result, they stand out in relief on weathered surfaces.

Sedimentary beds, which separate andesitic flows, consist of alternating bands of cherty argillite, conglomerate, breccia, quartzite, greywacke, and tuff. Individual units vary in thickness along strike and pinch and interfinger with lava flows indicating deposition in isolated basins.

Table of Formations

Time units	Formation and thickness (feet)		Lithology
Pleistocene and Recent	Glacial deposits		Sand, gravel, silt, glacial erratics
	Unconformity		
PROTEROZOIC	Mineralization		Veins containing quartz, carbonate, pitchblende, arsenides, sulphides and native elements
	Quartz stockworks		Hematite and copper-bearing giant quartz vein stockworks
	Diabase dykes and sheets		Fine- or medium-grained diabase, locally amygdaloidal
	Intrusive contact		
	Granite intrusives		Mainly massive biotite granodiorite locally porphyritic; related aplite dykes
	Intrusive contact		
	Granodiorite intrusives		Fine- to medium-grained granodiorite and diorite and associated aplite dykes
	Intrusive contact (?)		
	Quartz monzonite intrusives		Fine- to medium-grained quartz monzonite, minor granite and granodiorite, locally aplite dykes
	Intrusive contact		
	Porphyry intrusives		Feldspar-hornblende porphyry as sills, dykes and stocks; rhyolite porphyry–possibly extrusive
	Intrusive contact		
	Cameron Bay Group	1,000	Pebble- and cobble-conglomerate, ferruginous arkose, sandstone, greywacke, minor tuff, cherty argillite and porphyritic andesite

Table of Formations (Conc.)

Time units	Formation and thickness (feet)			Lithology
PROTEROZOIC	Unconformity (?)			
	Echo Bay Group	upper unit	5,000	Porphyritic, massive vesicular or amygdaloidal andesite flows, minor quartzite, argillite, tuff, conglomerate and breccia
				Massive crystalline tuff. Relationship not clear. Possibly intrusive into upper unit
		lower unit	4,500	Chert, cherty argillite, calcareous cherts, quartzite, argillite tuff, arkose, pebble-conglomerate, breccia, minor porphyritic andesites and trachytes

Cameron Bay Group

Rocks of the Cameron Bay Group are widely exposed between Lindsley Bay and Echo Bay. Brief notes on these rocks were made by Kidd (1932), Robinson (1933), Thurber (1946), Feniak (1947), and Fortier (1948). Due to erosion, the actual thickness of the group is not known but the most complete section, about 1,000 feet, is exposed near Cameron Bay. The first 500 feet of this section consists of poorly bedded pebble- and cobble-conglomerate and ferruginous arkose whereas the remaining 500 feet is made up of impure sandstones, greywackes, and, near the top, some tuffs, andesitic porphyries, and agglomerate. Cherty argillite beds have been reported by Fortier (1948) in the Glacier Lake area and cited as useful horizons in determining the structural trend of the Cameron Bay Group.

The conglomerates from lower beds are poorly sorted, loosely cemented rocks with reddish and maroon ferruginous arkosic matrix. The pebbles and cobbles generally consist of underlying older rocks; a large percentage of them are porphyritic andesites similar to those of the Echo Bay Group rocks. The conglomerates also contain small percentages of cherty argillite, quartzite, and occasionally, vein quartz, red-banded chert, granitic material, and pebbles of the older diabase sheet. The predominance of particular types of pebbles and cobbles in the conglomerate depends on the type of older rock units in the area and thus regional variations are more a rule than an exception. Pebbles, consisting of granitic material and vein quartz, in the Cameron Bay Group would suggest that at least some of the granitic bodies and quartz veins predate the period of deposition of the Cameron Bay Group conglomerates.

Most of the pebbles and cobbles in the conglomerate range from a quarter inch to 8 inches in diameter with a few measuring up to 20 inches across. The coarse cobbles are subrounded and the finer material is subangular to angular. The matrix of the conglomerates consists of fine-grained angular fragments of quartz and feldspar. The amount of induration of the conglomerates varies from one bed to another, but generally these rocks are poorly cemented and the pebbles and cobbles weather out rather readily.

Arkose beds, consisting of material similar to the conglomerate matrix, separate conglomerate horizons. These beds are several inches thick and contain, in addition to feldspar and quartz, occasional pebbles which are similar to those found in the conglomerates. Both conglomerate matrix and arkose contain about 6 per cent by weight heavy minerals which consist, in decreasing order of abundance, of anatase, epidote, Fe-Ti oxides, apatite, zircon, and rutile. The frequency distribution of these heavy minerals in the Cameron Bay Group rocks is almost identical to the frequency distribution of the same minerals in the lower members of the Hornby Bay Group conglomerates which outcrop north of the Port Radium map-area.

Interstratified with the conglomerate are several thin beds of grey, green, and brown argillite. Near the top of the section the Cameron Bay Group has a few bands of tuffaceous rock interlayered with the sedimentary members. The tuffs are fine grained, buff to black, and consist of angular fragments of feldspar, quartz, and dark green rock fragments all embedded in a reddish to black nearly cherty groundmass. The tuff and much coarser conglomerate outcrop intermittently and appear to grade laterally into arkose. In the Camsel River map-area, Parson (1948) reported that tuffs are present with the middle sedimentary members of the Cameron Bay Group. This would indicate that a considerable part of the stratigraphic sequence in the Port Radium map-area has been removed by erosion. Robinson (1933) estimated the thickness of Cameron Bay Group at 3,000 feet. If his estimate is accurate, then about 2,000 feet of the section has been eroded at Cameron Bay.

The relationship between the Cameron Bay Group and the Echo Bay Group has been of considerable interest to all workers in the area. Although the picture is not clear, most of those who mapped in the vicinity of Port Radium agree that the two groups are separated by an erosional interval and an unconformity. The evidence for this is mostly circumstantial and is based on the following differences between the two groups:

1. Echo Bay Group is made up predominantly of volcanic rocks and Cameron Bay Group is essentially sedimentary.
2. Sedimentary members from Echo Bay Group are well indurated and resistant to weathering whereas the Cameron Bay Group sedimentary rocks are poorly cemented and weather readily.
3. Cameron Bay Group rocks contain pebbles and cobbles which are mineralogically and compositionally identical to the rock units from Echo Bay Group.
4. When compared to Echo Bay Group conglomerates the character of Cameron Bay Group conglomerates indicates a period of rapid disintegration and deposition and little decomposition.
5. Cameron Bay Group conglomerates break around the pebbles whereas those from Echo Bay Group break through the pebbles.
6. The coloration and thickness of the two groups are diverse. Echo Bay Group conglomerates are dark coloured and thin bedded whereas the Cameron Bay Group conglomerates are reddish with poorly defined, thick bedding.
7. Cameron Bay Group rocks form gently dipping terraces with dips of less than 20 degrees and Echo Bay Group rocks have dips of more than 20 degrees.

Although these criteria seem to apply for the area near Port Radium they may not be valid for the region as a whole.

Intrusive Rocks

Feldspar–Hornblende Porphyry

Intrusive feldspar–hornblende porphyries, compositionally similar to the extrusive members of the Echo Bay Group volcanics, are common in the Port Radium map-area and form prominent hills and outcrops having well-developed blocky jointing. The largest belt of these rocks, about 2 miles wide, trends north–south in the eastern part of the map-area. Smaller bodies with dips between 20 degrees and vertical and having a configuration of dykes and stocks intrude older sedimentary and volcanic rocks throughout the Port Radium map-area. Similar porphyries have been reported to geologists as far south as Great Slave Lake, a distance of some 300 miles, and over a width of 40 miles. Almost all the porphyries parallel the structures of the older rocks indicating a major belt of weakness parallel to their strike. Although lithologically similar, the porphyries may represent more than one period of igneous activity. The bulk of the larger masses, however, appears to be contemporaneous and represents a major intrusive event postdating Echo Bay and Cameron Bay Groups.

Lithologically the porphyries are similar throughout large areas and are either grey, red, brown or purple. The phenocrysts constitute between 5 and 50 per cent of the rock and average about 20 per cent. Scarcity of phenocrysts is most noticeable along the contacts with older rocks and in bodies of very small extent. The phenocrysts, which measure several millimetres across, consist predominantly of oligoclase, andesine, and hornblende with subordinate amounts of albite, orthoclase, biotite, and locally, rounded quartz. Feldspar phenocrysts are better developed than hornblende and are altered to sericite or carbonate or replaced by chlorite. Hematite dusting of feldspars varies with the locality and accounts for the variation of colours from grey, where hematite dusting is slight, to red, where the dusting is intense. Hornblende is present in the matrix and as phenocrysts but minor, relative to feldspar. It is usually altered to chlorite or biotite or replaced by carbonate and leucoxene.

The groundmass, which is very dense, aphanitic, and constitutes up to 80 per cent of the rock, is made up largely of parallel or subparallel feldspar laths which swirl around phenocrysts. Hornblende, biotite, apatite, sphene, and magnetite constitute a minor portion of the groundmass.

Phenocrysts along the borders of larger masses or in smaller dykes are virtually lacking, but when present, consist almost entirely of plagioclase. The groundmass in such instances is generally coarser and much richer in the ferromagnesian minerals which make up from 30 to 50 per cent of the rock.

The proportion of phenocryst constituents and the ratio of phenocrysts to the matrix change from one area to another. Accordingly, the porphyries have been classified by geologists as rhyolite porphyry, granite porphyry, feldspar–quartz porphyry, feldspar porphyry, andesite porphyry, dacite porphyry, and other similar names.

Metasomatism, metamorphism, and deformation of older rocks are most intense along the borders of feldspar–hornblende porphyries. At LaBine Point the most intense metasomatic zones lie above the tops of the porphyry bodies. Close to their contacts the cherty rocks contain appreciable amounts of garnet and diopside and farther away they contain hornblende, biotite, and magnetite. Locally, the magnetite constitutes essentially a monomineralic assemblage a few inches wide. Several hundred feet away from the contact cherty rocks show no appreciable changes. In addition to the metasomatic and metamorphic effects the older rocks, along the contacts with the porphyries, have been brecciated, intricately folded, and recrystallized to coarser grained metasediments and metavolcanics. All these features suggest a magma of low viscosity with extremely pervasive characteristics which was injected forcefully by pushing aside pre-existing formations. In the areas observed, the porphyries are intruded by phaneritic rocks of granitic composition and, in a few localities, by dykes which are lithologically identical to the feldspar–hornblende porphyries.

Rhyolite Porphyry

Contemporaneous or nearly contemporaneous with the feldspar–hornblende porphyries is a group of rocks which Riley (1935) calls granite porphyry, but since the groundmass is aphanitic the term rhyolite porphyry would be more appropriate.

Rocks of this category underlie the shores of the mainland and some of the islands of Lindsley Bay. Riley (1935) notes that on its eastern side, the porphyry is intruded by a granite and on its western side it gives the appearance of being intrusive into older andesites, whereas Feniak (1952) provides evidence that similar porphyry is intrusive into granite. In many places the contacts between the porphyry and other rock types are difficult to find and the rocks give the appearance of merging into one another.

The monotonously massive porphyries outcrop as a group of hills which rises about 200 feet over the neighbouring granitic rocks. This physiographic expression is very diagnostic and erosional uniformity is attributed to similarities in texture, physical composition, and hardness. Well-developed, closely spaced, rectangular jointing accentuates the massive nature of the rocks, and this feature is seen along vertical cliffs where a third, and horizontal, set of joints imposes a stair-like effect. Many of the larger joints are often healed with quartz or carbonate material.

The porphyries have a dense groundmass which is commonly red, brown, and purple. The colour differences appear to be mainly a function of hematite dusting and groundmass minerals. Occasionally, faint, nearly horizontal banding may be detected by slight colour differences. Randomly distributed phenocrysts are invariably present and consist of yellowish, pink, or white feldspars, quartz, and minor mafic minerals. On close examination the fragmental nature of the leucocratic phenocrysts is distinct; instead of well-developed equidimensional forms they are sharply angular in outline with individual fragments ranging from 4 millimetres to minute specks. Where the fragmented phenocrysts are sufficiently abundant the rocks display a pyroclastic character. Texturally, the porphyries fall into two broad categories: aphanitic and crystalline. Aphanitic porphyries have a groundmass which is cryptocrystalline, whereas crystalline porphyries contain a uniformly microgranular groundmass. This breakdown is somewhat arbitrary because the two imperceptibly grade into each other.

The randomly oriented phenocrysts never exceed 50 per cent of the rock. In aphanitic porphyry the feldspar and quartz phenocrysts are irregular or angular and in the crystalline porphyry they are deeply embayed by lobes of the groundmass. In some crystalline porphyries this resorption effect is so intense that there is some gradation between the groundmass and phenocrysts.

The phenocrysts are plagioclase (An_{12}–An_{50}), K-feldspar, quartz, biotite, hornblende, and occasionally augite. Plagioclase averages about 20 per cent of the phenocrysts and is often altered to sericite, chlorite, epidote, and carbonate. When altered, it feels waxy and has a yellowish green cast with a dull lustre.

The content of K-feldspar and quartz phenocrysts never exceeds 20 per cent of the total phenocrysts. Both are irregularly angular to semirounded and embayed by the groundmass.

Rarely unaltered, biotite and hornblende constitute no more than 10 per cent of the phenocrysts. Frequently the former presence of ferromagnesian minerals is indicated only by an outline of black oxide granules and accompanying chlorite. In some samples hornblende and biotite occur in grains ranging in size from that of phenocrysts to that of the matrix. Occasionally, biotite can be seen enveloping feldspars or quartz as though it were compacted around them.

The groundmass accounts for up to 70 per cent of the rock and varies from cryptocrystalline in the aphanitic variety to distinctly granular in crystalline porphyry. It consists of a very fine mixture of K-feldspar and quartz grains which measure between 0.01 and 0.05 mm across. Greenish biotite of similar size usually accompanies K-feldspar and quartz in crystalline porphyry.

The crystalline porphyries, in position and texture, lie between aphanitic porphyries and granitic rocks. All three have an unusually close similarity, both in mineralogy (heavy minerals included) and specific gravities, that suggests very close affiliation. The gradual change in texture from aphanitic through porphyritic to hypidiomorphic granular, therefore, may be attributed to changes in conditions during emplacement of magma at three successive levels as well as subsequent modifications due to recrystallization. The aphanitic porphyries are presumed to have formed as a result of the initial breakthrough of a comparatively shallow acid magma chamber which, subsequently, forcefully rose to a higher level and invaded these porphyries causing partial recrystallization and partial stoping.

Granitic Rocks

Granitic rocks in the Port Radium map-area underlie about 45 per cent of the terrain and outcrop as masses ranging in size from several hundred feet to many miles across. Smaller bodies are generally located along the contacts and within the Echo Bay Group where they occur as stocks and plugs intruding Echo Bay strata. The largest granitic mass, measuring up to 6 miles wide, trends northward along the eastern edge of the map-area.

Based on mineralogy, granitic bodies in the Port Radium map-area are very similar to plutonic masses found in the McTavish Arm region. Figures 1 and 2, which include data from the Port Radium map-area, provide a summary of these variations for the granitic rocks from the McTavish Arm region. The data are based on randomly selected and widely spaced samples which were slabbed, stained for plagioclase and K-feldspar (Bailey and Stevens, 1960), and point counted. Although the granitic bodies may represent more than one period of the magmatic cycle, almost every unit throughout the district shows considerable variation in the major minerals and, depending on the degree of this variation, the rocks range between true granites and diorites. The most common rock type is quartz monzonite (*see* Fig. 2).

Granitic rocks exhibit a diversity of composition, texture, and structure. Although they are mostly massive, gneissic varieties are reported to be present along contacts with older sedimentary and volcanic rocks. These gneissic varieties normally do not form mappable units.

Granitic rocks in the Port Radium map-area intrude Echo Bay and Cameron Bay strata, and are believed to be younger than the previously described feldspar–hornblende porphyries. On the basis of continuity, crosscutting relationships, and textural and mineralogical peculiarities, the granitic rocks in the area can be divided into several general groups each of which is treated separately.

Quartz Monzonite

Perhaps the oldest sizeable intrusive body in the area is pink weathering quartz monzonite (Feniak, 1947), located about a mile west of Gossan Island on Dowdell Peninsula. Most of this intrusion is medium grained, pinkish, and contains pink orthoclase, greenish plagioclase, quartz, and hornblende. The accessory minerals are magnetite–ilmenite, zircon, apatite, sphene, and rutile. Along the borders the quartz monzonite grades into porphyritic and then into aplitic facies which contain relatively large percentages of plagioclase and hornblende. The aplitic facies in turn often grade into volcanic rocks so that the contacts between the two can seldom be determined within several feet. These contacts are normally marked by alteration and bleaching of the country rock and are roughly peripheral to the intrusive masses. The most intense alterations are found along the eastern side of the quartz monzonite complex.

Granodiorite

Several bodies of granodiorite, locally grading to darker coloured quartz diorite and less commonly into lighter coloured quartz monzonite, cut the Echo Bay Group rocks and feldspar–hornblende porphyries. The largest of these occurs on the peninsula southwest of Lindsley Bay and the smaller one, measuring about a half mile wide, is between Great Bear Lake and Mile Lake in the extreme southwest corner of the map-area. Furnival (1939) described a petrologically similar granodiorite between Contact Lake and the east arm of Echo Bay. This intrusion is about 5 miles long and up to 1½ miles wide. A very small stock of granodiorite, which is very similar to those mentioned above, is located along the south shore of Echo Bay about a half mile east of Bolger Lake[1]. At this locality dyke-like apophyses protruding from the granodiorite stock cut the neighbouring quartz monzonite suggesting that the granodiorite is younger than the quartz monzonite described above. Based on the texture, the granodiorite can be divided into coarse and fine phases.

The coarse phases of the granodiorite are generally some distance from the contacts of older rocks. They are light to medium grey or light brown and medium to coarse grained but distinctly coarser than the older quartz monzonite described above. They are also distinguished from the older quartz monzonite by being darker and by having a rough pitted weathered surface. However, where the granodiorite grades into the quartz monzonite facies it is petrologically indistinguishable from the quartz monzonite.

The coarse phase of the granodiorite contains sericitized plagioclase (An_{27-48}), kaolinized orthoclase, hornblende, quartz, biotite, and occasionally augite. Accessory and secondary minerals consist of apatite, zircon, sphene, magnetite–ilmenite, chlorite, epidote–zoisite, and carbonates. The proportions of plagioclase, orthoclase, and quartz are not constant and, depending on the amounts of these minerals, normal granodiorite may grade into quartz diorite or quartz monzonite. The quartz content averages about 10 per cent but may, in places, be as high as 25 per cent or as low as 5 per cent. In some localities it occurs as micrographic intergrowths with orthoclase or as a replace-

[1] Unofficial local name.

ment of plagioclase. Although hornblende is the most common ferromagnesian mineral, colourless augite can be found in the quartz diorite facies as a relict mineral within hornblende or biotite or chlorite.

TABLE II *Modal analyses of granodiorite based on four widely separated samples (%)*

Plagioclase	27.2–53.8
Orthoclase	8.1–28.1
Quartz	13.9–24.9
Hornblende	11.8–19.2
Biotite	1.0– 5.6
Chlorite	2.0– 3.4
Accessory minerals	0.5– 2.0
Anorthite content 27–48	
Density of rocks 2.73–2.77	

Table II lists modal analyses, based on thin-section counts, of four widely selected samples of the granodiorite, and Table III gives chemical analyses for two samples collected south of Mile Lake. These samples were collected approximately 3 and 35 feet from the contact of a younger granite. The chemical results indicate that at 35 feet from the contact the granodiorite shows a slight increase in SiO_2, Al_2O_3, NaO, TiO_2, and P_2O_5, and a slight decrease in MgO, CaO, and MnO. In general, however, there is no substantial evidence that the younger granitic magma caused modifications along the intrusive contacts with the granodiorite.

Spatially associated with the coarse phase granodiorite are finer phases which occupy an intermediate position between the older Echo Bay Group rocks and the more central parts of the granodiorite bodies. The fine phases are most prominently developed with the granodiorites that stretch along a belt lying between Cameron Bay, Glacier Lake and Great Bear Lake. For the most part these rocks are finer grained, lighter coloured, and contain lesser amounts of ferromagnesian minerals than do the coarse phases. They are also more heterogeneous mineralogically and compositionally vary from syenite to granite to granodiorite.

Furnival (1939) reported that the older rocks which border the granodiorite have been metamorphosed along the contacts. The aureoles extend up to a quarter mile into host rocks and consist of chlorite, actinolite, epidote, disseminated pyrite, and magnetite. Pyrite, through weathering, forms extensive yellow and brownish gossans along the contacts. The development of a metamorphic halo, predominantly along the eastern side of the granodiorite bodies, seems to indicate that the granodiorite underlies the older rocks and that it dips east at a shallow angle.

Several monzonite porphyry dykes, probably related to a granodiorite magma, are present along the western contact of the Dowdell Peninsula granodiorite. These dykes are steeply dipping, between 30 and 70 feet wide, and are characterized by rounded quartz phenocrysts. They are pink and are finer grained than the granodiorite. Some can be traced across the sedimentary sequence of the lower unit of the Echo Bay

Group which lie to the west and into the granite which occupies the area of Dowdell Point where they terminate. This relationship suggests that this monzonite and similar bodies in the area are younger than the granodiorite.

TABLE III *Chemical analyses of granodiorite near Mile Lake (%) (after Feniak, 1947)*

	(1)	(2)
SiO_2	58.84	59.15
Al_2O_3	15.40	16.18
Fe_2O_3	0.84	0.99
FeO	6.17	5.89
MgO	4.59	3.80
CaO	4.81	3.68
Na_2O	2.56	3.68
K_3O	4.43	4.23
H_2O	1.46	1.47
H_2O	0.09	0.06
TiO_2	.61	.72
P_2O_5	.20	.30
MnO	.20	.15
	100.20	100.30

(1) Granodiorite collected 3 feet from a younger granite contact.
Analyst: M. Feniak.

(2) Granodiorite collected 35 feet from the granite.
Analyst: A. S. Fryxell.

Granite

Intruding all rock types previously described are extensive granite bodies which range in composition from granite to quartz monzonite. A part of such a granitic mass, which extends for about 30 miles to the south beyond the map-area, outcrops at Dowdell Point and is about a mile wide. Similar rocks which probably represent a northern extension of the Dowdell Point granite outcrop along the islands west and north of LaBine Point. A most extensive and continuous body of similar rock types occupies about a third of the eastern part of the map-area.

Despite the large areal extent these rocks are very similar. They are, for the most part, massive with a characteristic coarse-grained porphyritic texture except along the contacts where the textures are finer and often porphyritic. The rocks often weather to rubble and are generally pinkish. In places they resemble a rapakivi type of granite principally because of rim-like rows of plagioclase around orthoclase crystals.

The rocks are characterized by subhedral to anhedral and slightly perthitic pink orthoclase crystals which measure up to three quarters of an inch. The subhedral shapes are present mainly where the textures are relatively coarse and where the ratio of orthoclase to plagioclase is high. Plagioclase is much smaller than orthoclase (about 5 mm) but is more anhedral and white or faint yellow. It has an anorthite content between An_{11} and An_{40}. Zoning in plagioclase is rare but, when present, the compositional difference between the outermost and innermost zone does not exceed 5 per cent of anorthite. Sericitization of plagioclase is common but such alteration is less intense than in other types of granitic rocks.

Subhedral to irregular green hornblende and biotite crystals measure up to 5 millimetres across and are at least partly altered to chlorite, especially in finer grained varieties. Epidote, occurring as scattered clusters or minute veinlets, is an accompanying product of chlorite. Anhedra of clear quartz several millimetres in diameter are invariably interstitial though occasionally the coarse-grained varieties also contain bluish quartz which is larger and subhedral. In places micrographic textures, due to intergrowth of quartz and orthoclase, have been observed. Accessory minerals consist of apatite, zircon, sphene, fluorite, magnetite–ilmenite, and allanite. The degree of mineralogical variation for these rocks obtained from counting of six thin sections is shown in Table IV.

TABLE IV | *Modal analysis of granite based on six widely separated samples* (%)

Plagioclase	15.6–44.0
K-feldspar	19.6–43.6
Quartz	22.0–34.3
Hornblende	0.1– 5.2
Biotite	0.3– 3.2
Chlorite	4.2– 6.2
Accessory minerals	0.7– 1.8
Anorthite content	An_6–An_{40}
Density of rocks	2.63–2.72

On Dowdell Point and in the vicinity of LaBine Point the granite is in sharp contact with Echo Bay sediments. The borders are marked by partly digested xenoliths and schlieren of older rocks over a width of several hundred yards. Intrusion of granite at LaBine Point has so tilted and locally folded host rocks that the adjacent argillites are sometimes vertical and contorted. At this locality the contact of the granite strikes northeast and dips about 75 degrees to the east.

Aplite dykes are generally associated with the granitic masses but pegmatites are rare. Aplites are generally several feet wide, have steep dips, and strike at right angles to the granite contacts. Campbell (1955) reported the following range in the composition for these aplite dykes: orthoclase and microcline, 35-60 per cent; quartz, 35-60 per cent; oligoclase, 0-10 per cent; chlorite and epidote, 0-5 per cent.

Metamorphic effects of the granite on the country rock are negligible except for slight recrystallization along the contact and, unlike the feldspar–hornblende porphyry and granodiorite bodies, these granitic rocks do not have metasomatic aureoles.

Basic Dykes and Sheets

Basic dykes and sheets are the youngest intrusive rocks in the map-area. The steeply dipping dykes, ranging in width between several and 200 feet, preferentially occupy the east–west and north–south trending fractures but deviate locally and occupy the northeast-trending shear zones. The dykes appear to be earlier than some of the faults of the district and later than others. They are, however, earlier than much of the movement on faults which formed channelways for mineralizing solutions.

Diabase sheets outcrop mainly along the east shore of Great Bear Lake. They are sill-like and thus concordant with the stratified, relatively flat-lying rocks but dyke-like where they cut across intrusives and highly folded stratified rocks. In both cases they maintain shallow dips and nearly the same elevation. Except for slight local pinches and swells, the sheets have a consistent thickness of about 200 feet. Across faults diabase sheets are fractured and veined but show no displacement. Therefore, the sheets, like the dykes, were emplaced after the period of major faulting but before the period of mineralization. As far as could be determined, they are genetically closely related to diabase dykes.

Columnar structures, well displayed in sheets, are lacking in dykes. The country rock that adjoins the dykes and sheets has not been altered except for occasional reddening up to 20 feet from the contact. Dykes and sheets usually have chilled edges and sharp contacts.

Lithologically both dykes and sheets are identical. The rocks are greenish but brown when weathered and uniformly medium grained with diabasic textures except near borders where they are fine grained and occasionally amygdaloidal. They consist of nearly equal amounts of plagioclase (45%) and augite (45%), minor biotite (5%), and interstitial micrographic intergrowth of quartz and albite (5%). Orthopyroxene has been reported in some thin sections from the sheets. Secondary minerals consist of hornblende, chlorite, carbonate, sericite, leucoxene, magnetite, and hematite. Partly altered plagioclase (An_{70-73}) forms elongated euhedral grains which in places grade into a micropegmatitic groundmass. Plagioclase twinning is according to the albite and albite–Carlsbad laws. Euhedral to subhedral, occasionally twinned and about half-altered to uralite, augite shows only slight ranges of 2V z (49°–58°) and Z c (40°–48°). Biotite is a deep reddish brown variety. Although pyrite, sphene, and chalcopyrite have been reported the only common nonmagnetic heavy minerals, apart from pyroxene, are:

	Dyke (%)	Sheet (%)
Apatite	12	5
Opaque oxides	3	8
Zircon	2	—

Feniak (1947) collected samples from near the bottom, middle, and top of the diabase sheet but found no significant differences in mineralogy except for lower content of quartz near the bottom.

Massive Crystalline Tuff

Just north of LaBine Point and extending for about a mile is a homogeneous massive body of rock which has been mapped as crystalline tuff (Bateman and Jolliffe, 1944). The relationship of this tuff to neighbouring rocks is not quite clear but

Campbell (1955) has placed it stratigraphically between the lower and upper units of the Echo Bay Group, an assignment based on detailed work done at the Port Radium mine where the tuff cuts through the lower members of the Echo Bay Group rocks.

The tuff is a uniformly massive, dense, dark grey rock with sugary texture and grain size less than 0.5 mm across. It shows no sorting and when seen in thin sections individual mineral grains give the appearance of being fused, probably as a result of recrystallization.

Massive crystalline tuff is generally monomineralic with plagioclase as a main constituent. Locally it may also contain small amounts of quartz and orthoclase. Where it has been modified by hydrothermal and metasomatic solutions it contains magnetite, hornblende, and chlorite. In the field it may be confused with the fine-grained phases of feldspar–hornblende porphyry, but the latter generally has phenocrysts and contains ferromagnesian minerals as primary constituents.

The origin of massive crystalline tuff is puzzling and Campbell (1955) offered a fairly detailed treatment of this subject and concluded that the area underlain by tuff may represent a caldera or explosive vent. This conclusion was based on detailed structural work at Port Radium and comparisons with typical vents and calderas in other parts of the world. The presence of identical tuff beds towards the top of the section of the lower unit of the Echo Bay Group would suggest that the vent was formed before that time. This, and possibly other similar vents, appear to have been intermittently active and supplied tuffaceous material throughout the period during which the Echo Bay Group and the Cameron Bay Group strata were deposited.

Quartz Vein Stockworks

Closely associated with the northeast-trending faults and fractures and cutting through all rock types mentioned above are 'giant' quartz vein stockworks. The more prominent outcrop as white ridges that can be traced for miles. More than eighty of the larger veins have been mapped in the Great Bear Lake region but many others with similar trends are, no doubt, present. Veins of this type have been observed by geologists throughout the central District of Mackenzie and one of them has been described in some detail by Furnival (1935).

The veins are similar in character; all of those shown are steep dipping and measure between 100 and 500 feet across. Two parts can usually be recognized: a central part consisting of relatively massive quartz with minor amounts of vein breccia and an outer zone made up of white quartz stringers lacing country rock. The quartz of the central part is light grey. It has been brecciated at least three times and each time healed by white, sometimes vuggy, quartz veinlets similar to those of the outer zone. The last period of brecciation and quartz veining was accompanied by deposition of specular hematite, pyrite, copper sulphides, and, locally, pitchblende. The pitchblende deposits at Port Radium appear to be related to this phase of mineralization which itself is divisible into five separate states (Campbell, 1955).

Alteration of wall-rock along the quartz veins extends for up to 100 feet. Mafic constituents are intensely altered to chlorite and carbonate; the plagioclase is altered to carbonate, epidote, sericite, and chalcedonic quartz. Original quartz is strongly undulose. Near the vein the rocks become bleached and consist primarily of chalcedonic quartz and some shredded chlorite. Where mineralized, the veins are fringed by argillic and chloritic alterations.

Minerals other than quartz are sparse. They are specularite, bornite, chalcopyrite, covellite, chalcocite, pyrite, famatinite, siderite, and occasionally pitchblende. None of these minerals are present in quantities large enough to constitute an economic ore deposit.

Furnival (1935) provided a detailed description of one of the quartz vein stockworks known as "Sloan Dyke" and since his account pertains to the majority of similar veins some general features are worth mentioning.

"Sloan Dyke", which outcrops on Quartz Island[1] just north of LaBine Point, has been traced for some 50 miles to the northeast. It occupies a steeply dipping northeasterly trending fault zone which strikes between north 30 degrees east to north 60 degrees east. The main part of the vein is composed of massive and banded quartz.

Massive quartz is milky and granular, nonuniform in texture, and contains fragments of plagioclase which have been altered to kaolinite. It also contains inclusions of other minerals which are too small for identification. Euhedral crystals of quartz which line the walls of cavities and chalcedonic quartz are found with the massive variety. The latter contains an appreciable amount of chloritic material which accounts for the pale green colour of the chalcedony.

The banded quartz consists of alternating bands up to a quarter inch wide of milky and transparent quartz. The banding appears to be due to preferential distribution of liquid and solid inclusions. The solid inclusions consist of micaceous minerals some of which have been identified as chlorite and sericite.

On the basis of the crosscutting relationship three ages of quartz deposition are evident. The banded quartz fills fractures in the massive quartz and thus is definitely later than the massive variety.

Following the third period of quartz deposition specular hematite was introduced along newly developed fractures and subsequent readjustment provided room for deposition of small amounts of chalcopyrite, bornite, chalcocite, famatinite, pyrite, siderite and, locally, pitchblende.

Along the margin and for up to 100 feet from the vein the country rock shows various stages of alteration. Feldspars are usually altered to sericite and ferromagnesian minerals to chlorite, calcite, quartz, and magnetite. Where the alteration is complete, chalcedony replaces secondary minerals and quartz veinlets lace the rock. Furnival (1935, p. 853), on the basis of chemical analyses of fresh and altered granodiorite, concluded that during the alteration of granodiorite by the vein-forming materials all major oxides except Fe_2O_3, SiO_2 and H_2O were removed from the granodiorite.

Metamorphism and Alteration

Metamorphism in the Port Radium area is dominantly related to hydrothermal activity although locally thermal and retrograde stages can be connected to intrusive bodies. The last two are related to intrusions which postdate Echo Bay Group rocks. The most detailed and comprehensive account on metamorphism and alteration for the LaBine Point area was given by Campbell (1955). There and elsewhere in the district calcareous cherts have been converted to a mixture of pyroxene, garnet, diopside, and scapolite whereas the cherts, especially the fine-banded types, have been converted to aggregates of pyroxene, amphiboles, feldspars, and magnetite. This metamorphism

[1] Unofficial local name.

and the resulting products are principally related to the feldspar–hornblende porphyry intrusives.

The degree of metamorphic intensity varies with the locality and the type of intrusive. On Dowdell Peninsula the granite is in sharp contact with the banded argillites of the lower unit of the Echo Bay Group indicating that emanations from the granite magma were not intensive and, based on the absence of pegmatites, that the magma was relatively dry. The major contribution of this granitic magma to the surrounding rocks was in the form of aplites and possibly quartz veins. Depleted silver deposits at Bonanza[1] and at Contact Lake suggest that carbonate and metallic minerals may have been derived from this granite. At some localities hornfels was produced along the contacts with granites whereas in others there is evidence that quartz and orthoclase may have been added.

Of all the granitic masses the relatively older quartz monzonite and granodiorite stocks have produced the most intensive effects on the adjacent volcanic rocks. In many places the older fine-grained volcanic members have been recrystallized to coarse assemblages so that their textures are nearly identical with those of the intrusives. In such instances the contacts between the two are poorly defined and marked by gradational zones measuring tens of feet wide. There is field evidence which suggests that the effect of recrystallization has been more pronounced on the upper parts of the flows than on the lower parts. Where the older granite intrusives are in contact with cherts and cherty argillites the latter rocks show evidence of recrystallization and are marked by appreciable development of dark minerals, especially hornblende.

Widespread introduction of pyrite, which gave rise to the extensive gossans, appears to be genetically related to the quartz monzonite and granodiorite intrusives and not to the solutions which may have permeated along faults and shear zones. This is borne out because Gossan Island is separated from similar gossans on the north side of Reid fault by the same distance as that separating the faulted parts of the quartz monzonite and granodiorite complex.

Pyrite has been extensively introduced along the minute fractures of older rocks and has penetrated them in an extremely pervasive manner. The halo of pyritization is most intense along the eastern borders of the intrusive where it measures up to a half mile wide.

A striking feature of the area is the introduction of vast amounts of ferric iron oxide which accounts for the purplish cast of nearly all rock types. This hematite alteration is prevalent throughout the district but its intensity varies. It is most pronounced at LaBine Point where cherty members of the Echo Bay Group have been converted to a very dense reddish jasper.

Hydrothermal wall-rock alterations which have a spatial connection with the mineralized veins are widespread along the shear and fault zones and from the oldest to youngest consist of red alteration, argillite alteration, chloritization, and carbonitization (Campbell, 1955).

Red alteration refers to staining, impregnation, or replacement of original minerals by hematite in dust-like particles. It affects all rock types but is most extensive in cherty members of the Echo Bay Group and in feldspar–hornblende porphyry. The widespread occurrence of this alteration implies that the redistribution of iron from iron-rich sediments was accomplished by a combination of metamorphic and hydrothermal processes. Numerous references have been made in the literature to the

[1] Unofficial local name.

association of red alteration with pitchblende deposits, but at the Port Radium mine there is only a cursory connection between the two although some of the richest ore shoots are flanked by red alteration.

Argillic alteration overlaps and supersedes red alteration and constitutes the most common type of alteration along vein zones at the Port Radium mine. It affects all rock types and reduces them to a grey or greenish aggregate of clay which consists of montmorillonite, illite, kaolinite, and variable proportions of chlorite and sericite. Cherty rocks are most intensely affected by argillic alteration and in decreasing order of intensity are followed by diabase, feldspar–hornblende porphyries, metasomatized sediments, and granitic rocks. More intense alteration occurs along bedding planes, joints, and fractures suggesting that the permeability of the rocks was as important as the composition.

Chloritization is not as widespread as argillic alteration but is closely associated with argillic as well as carbonate alteration. It is often present at the outer fringes of argillic alteration zones where it can be distinguished by a greenish streak. Chloritization is most intense and widespread in rocks high in ferromagnesian minerals. Such minerals are replaced by chlorite before feldspar and quartz are affected. This replacement is generally pseudomorphic or, where the alteration is more intense, takes the form of irregular patches distributed throughout the rock.

Carbonates are intimately intermingled with the argillic and chlorite zones but where they constitute up to 60 per cent of the rock they form alteration zones of their own. In such instances carbonate occurs as fine-grained flakes distributed randomly throughout the rock although it preferentially replaces ferromagnesian minerals. The carbonate alteration extends for greater distances from the veins than any other alteration cited above.

Structure

Structures in Sedimentary and Igneous Rocks

The regional structure of stratified rocks is a homocline, which, depending on the locality, strikes either in a northwesterly or northeasterly direction and dips 35 to 70 degrees towards the east. Locally, however, the structures are quite complex, especially near the younger intrusive bodies.

Near granitic intrusives and feldspar–hornblende porphyries the beds of the Echo Bay Group are highly folded and vertical with a number of tight folds and small-scale dislocations. Brecciation often accompanies small-scale folding and inclusions of older rocks in granite are rather common. On a larger scale, e.g., in the area east of Glacier Lake and east of Dowdell Point, the strata conform in trend with the outline of the intrusions indicating a forceful injection and pushing aside of the older rocks. Away from the contacts small-scale open and isoclinal folds have also been recorded suggesting that there may be larger structures with similar geometry but these cannot be verified because of the absence of distinct marker beds.

Cherty members of the Echo Bay Group are intricately fractured and show displacement of several feet along joint-like planes. These structures appear to predate the main period of deformation and are probably related to the intrusion of feldspar–hornblende porphyries.

Lower sedimentary members of the Echo Bay Group are often ripple-marked and crossbedded and show graded bedding being coarser and darker coloured at the base and finer, lighter coloured, near the top. Cherty argillites, in a few places, show cavernous structure due to a minor amount of calcareous material. At Mystery Island, Thurber (1946) reported spherical to elongated structures roughly parallel to the bedding of the cherty rocks which appear black on weathered surfaces. These bodies are 1 to 4 inches in diameter and as much as 1½ feet long. On freshly broken surfaces these structures have been shown to consist of spherical aggregates of chlorite. The evidence as to whether the structures represent algal growth or are due to differential weathering is inconclusive.

Structures in volcanic rocks are relatively simple and consist of amygdules, fragmented material, and fluxion-arranged phenocrysts around the fragments. The last feature would suggest that the lava was forced through restricted channels along which fragmentation of the wall-rock took place. Flow breccias are common at the surfaces of the flows indicating an overriding effect of younger flows over hardened surfaces of older flows. Large phenocrysts and amygdules in the upper unit of the Echo Bay Group are normally aligned parallel with the strike of the flows although locally there are variations in trends, presumably due to irregular flow or to turbulence.

In comparison to the Echo Bay Group, rocks of the Cameron Bay Group display very simple structure. For the most part they trend towards the northwest or northeast and dip either towards the east or towards the west at angles ranging from 5 to 35 degrees. The general picture is that of a series of open anticlines and synclines with axes plunging at low angles either to the north or to the east.

The structural relationship between the Echo Bay Group and the Cameron Bay Group has received much attention and has been a controversial issue, principally the question of whether the Echo Bay Group–Cameron Bay Group contact is conformable or not. As has been mentioned earlier in this report most geologists favour an unconformity.

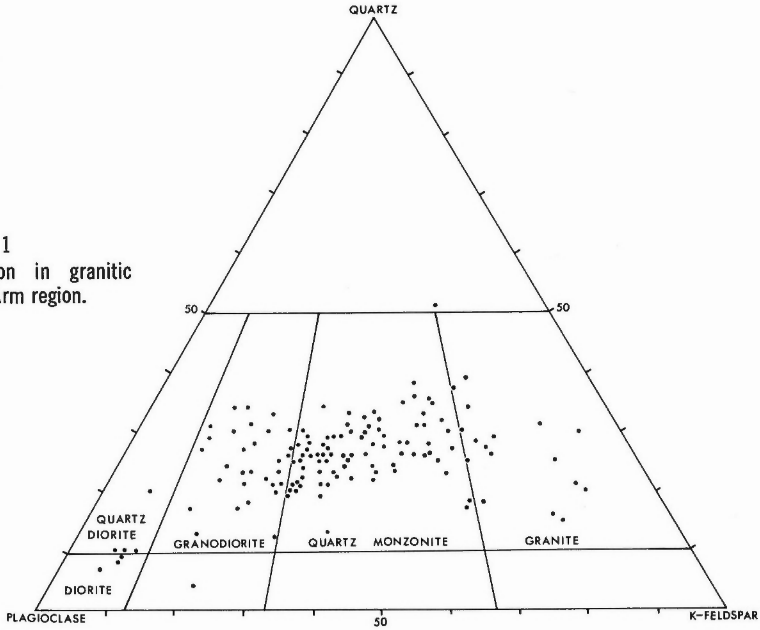
Granite bodies are generally massive and show no alignment of platy minerals. They form sharp contacts with the rocks which they intrude and along the margins often contain rounded xenoliths and hazy schlieren. Small apophyses of granitic material may grade into irregular aplite dykes.

Intrusive feldspar–hornblende porphyries and, to a lesser degree, granitic rocks show two sets of vertical joints, one of which is strongly developed. Where the rocks are fine grained the joints are spaced several inches apart and where the textures are coarse the spacing is measured in feet. These joints and nearly horizontal sheeting planes account for the characteristic stair-like effect on hillsides. Similar step-like surfaces are present in diabase sheets, but there they are much better developed principally due to strong columnar jointing.

Fracturing

Shears and faults constitute a major structural feature in the district. On aerial photographs the more significant fractures appear as strong lineaments marked by depressions with narrow lakes or rivers and nearly vertical cliffs. They are often occupied by quartz veins or diabase dykes and, where the fractures underlie drift-filled lineaments, their presence is suggested by the abundant brecciation and hydrothermal alteration of wall-rock.

FIGURE 1
Compositional variation in granitic rocks from McTavish Arm region.



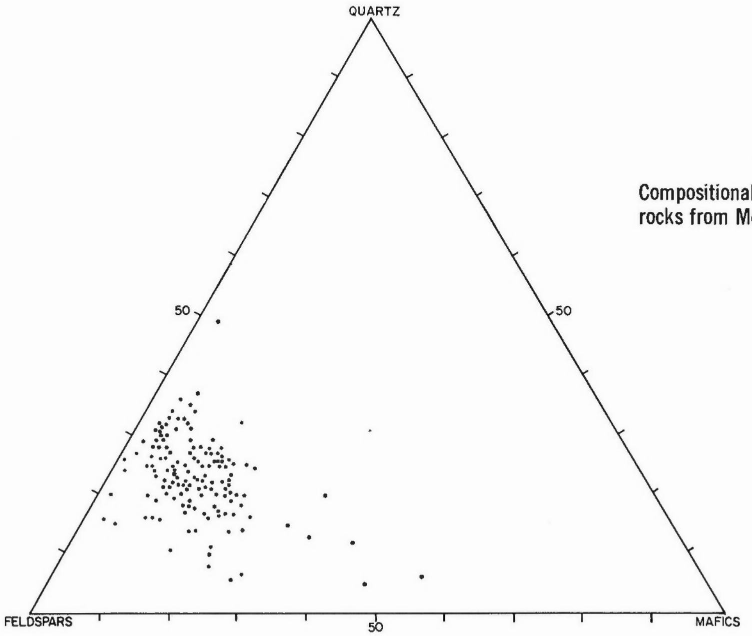


FIGURE 2
Compositional variation in granitic rocks from McTavish Arm region.

The most widespread pattern of fracturing is a system of steeply dipping northeast-trending faults and shears with compound branches. This direction of failure is typical for fractures as short as only several hundred feet. As in the McTavish Arm district (Fig. 3) the largest number of fractures in the Port Radium map-area have strikes ranging from north 20 degrees east to north 60 degrees east. Five prominent, nearly parallel fracture systems of this type are spaced about 3 miles apart and each measures up to 15 miles long. One, known as Reid fault, passes through Echo Bay, Cameron Bay, and the southeast end of Mackenzie Island and Vance Peninsula. This fault has an apparent horizontal displacement, as indicated by matching gossan zones and granite bodies, of about 2 miles with the northern block moving east relative to the southern block. There is no definite information on the amount of vertical movement along this fault nor conclusive evidence as to which side moved downward. Faults which trend subparallel to Reid fault show smaller right- or left-hand displacements; the apparent anomaly being, no doubt, due to the vertical component of faulting, which on the basis of differences in displacement between dykes and moderately dipping sediments, is estimated to be about several hundred feet.

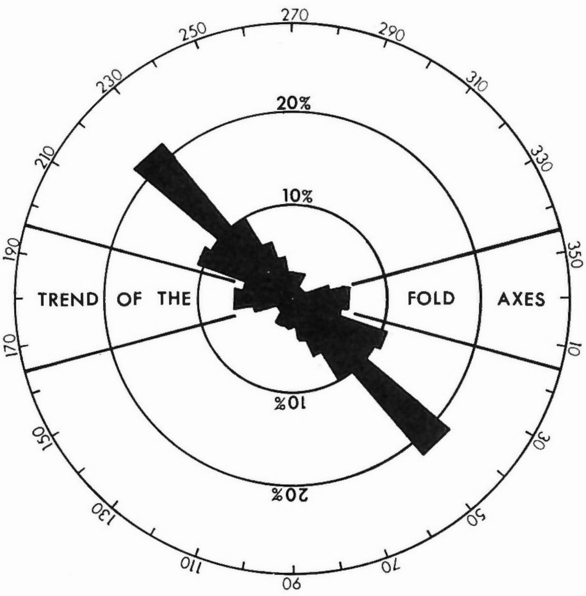


FIGURE 3
Diagram showing the relationship between strike intensity of major fractures and the trend of the fold axes.

Complementary to the northeast-striking faults is a set trending northwest. They are poorly developed and show negligible left-hand displacement. To the south of the map-area, however, left-hand displacements of several miles have been reported. Two additional sets, one with east–west and the other with north–south trend, are similarly inconspicuous though their presence is often confirmed by the diabase dykes which occupy these sets. It may be of significance that the pattern of fracturing in this area is very similar to that observed throughout the central District of Mackenzie (Wilson, 1948) and as far south as northern Alberta (Godfrey, 1958).

Attempts to explain the origin of folding and fracturing in terms of a single orogeny may be naive due to complications that can arise from the superposition of patterns produced by more than one disturbance. Although the evidence at Port Radium mine indicates a complex history with at least four periods of fracturing (Campbell, 1955), the forces postulated here may suffice to explain the general pattern. As can be seen from Figure 4, the largest number of fractures in the region have strikes ranging from north 40 degrees to 50 degrees east. This diagram also shows that the axes of folds trend nearly north–south. The folding, which in all instances predates fracturing, would indicate maximum stress acting in the east–west direction. With this in mind, the pattern of northeast- and northwest-striking faults fits the theory of faulting mechanics well as predicted by Anderson (1951). He indicated that the shear failure will occur in rocks along 45 degree planes of maximum tangential stress but pressure across the fault plane tends to make shear failure along it less likely, thus making an angle smaller than 45 degrees with the major axis of stress. The direction of maximum pressure that could have produced the folding and fracturing in this area would have been east–west.

Two sets of fractures, one with essentially a north–south and the other an east–west strike, form acute angles with the master northeast-trending faults. Three

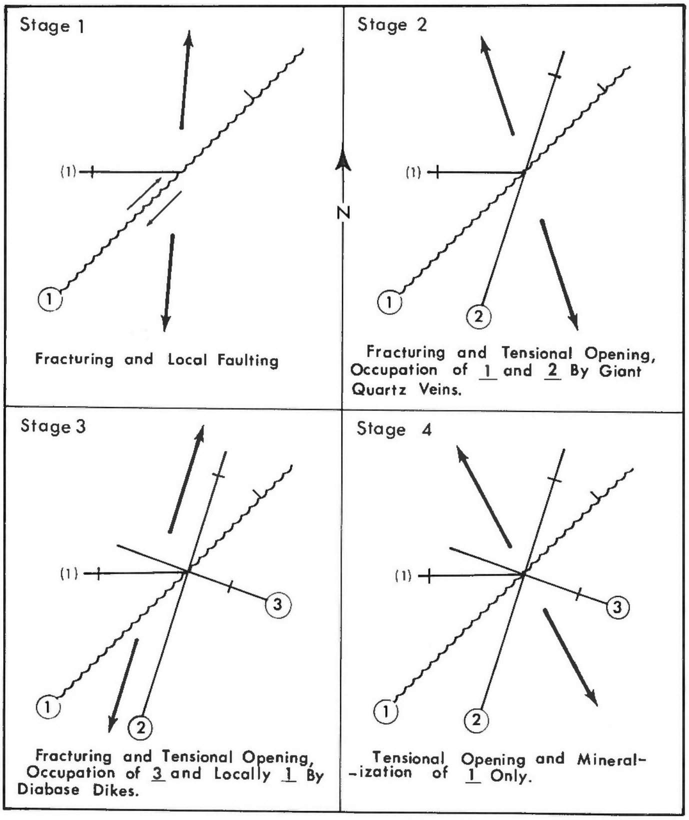


FIGURE 4
Stages of tensional stress on formations in McTavish Arm area (adapted from Campbell, 1955).

possible interpretations for these two sets are: (1) conjugate shears, (2) shears of the second order, (3) tension fractures. McKinstry (1953) has shown that so-called conjugate shears and tension fractures often turn out to be shears of the second order. Satisfactory interpretation, however, cannot be made from the geometry alone and additional evidence, either from the physical nature of the fractures themselves or from the sense of displacement along them, is required. Based on the available evidence, tension fractures appear to be the most plausible explanation in the Port Radium area.

Campbell's (1955) work at the Port Radium mine revealed that, following the major northeast fracturing, three periods of tension, each with a different direction, were active in the district (Fig. 4) and he provides the following explanation:

> It is evident that following the major northwest faulting in the district, tensional forces opened the shear zones thus formed and provided ingress for diabase magma and quartz-rich solutions. This tensional force that formed the north-northeast set of fractures occupied by the giant quartz veins would have had considerable dilatory effect on the northeast-trending main shear zones which are at a slight angle to the north-northeast system. For this reason the giant quartz veins not only preferentially occupy the north-northeast set of fractures but also occupy, to a considerable degree, some of the major northeast-trending shear zones. The tensional forces that resulted in the formation of the east-southeast set of fractures occupied by the diabase dykes were acting nearly parallel to the major northeast-trending shear zones and thus would have minor dilatory effects on them. For this reason the diabase dykes generally cut sharply across the northeast-trending shear zones and occupy them only for short distances and at widely scattered localities. The diabase dykes cut the giant quartz veins therefore the tensional forces acted first in a NW-SE direction, opening the north-northeast fractures and the major shear zones for occupation by the giant quartz veins, then acted in a SW-NE direction, opening the east-southeast fractures for occupation by the diabase dykes. At a still later period the tension was again acting in a NW-SE direction and reopened the northeast-trending shears and fractured the diabase dykes that had occupied and crossed them. There is good evidence that the last tensional action that opened the zones was one of relaxation with accompanying dipslip on some of the faults.
>
> From the foregoing discussion it is apparent that, following the initial northeast shearing, the formations in the McTavish Arm area were subjected to at least three periods of tension and that the directions through which the tensional forces acted varied from one period to the next. The northeast-trending fault zones that comprise the initial major deformation are right-hand normal faults. They were probably the result of north-south acting tensional forces.
>
> The pitchblende mineralization occurred during the fourth stage, when the northeast-trending zones were opened and the giant quartz veins and the dykes were fractured. Pitchblende is therefore found not only in the northeast-trending vein zones but also in northeast striking fractures in both the diabase dykes and the giant quartz veins in the vicinity of the major zones.

The main period of fracturing in the Port Radium map-area took place after the emplacement of granite rocks. At Port Radium the pitchblende veins, which occupy one of the last periods of fracturing, have been dated at about 1,400 m.y. (Campbell, 1955), whereas the granite which is cut by these veins has been dated at about 1,800 m.y. (Jory, 1964). The fracturing, therefore, occurred between these dates.

Chapter III

ECONOMIC GEOLOGY

Prospecting and mining have been the only important activities in the Port Radium map-area. The peak of this activity was reached during 1931 when some 3,000 claims were staked. During the years that followed additional staking was done and the entire area was thoroughly prospected by conventional and geophysical methods. Promising prospects were tested by trenches or in some cases by drillholes. The primary search from 1930 to 1944 was for silver and from 1944 to 1960 for uranium and other mineral deposits. Most of the surface work was done before 1934.

Almost all known mineral prospects and commercial ore deposits are of a hydrothermal type and occur as fissure fillings along fracture zones. The veins may be hundreds of feet across, as in giant quartz stockworks described earlier, or a fraction of an inch as in the joints. In both instances the principal and most abundant minerals are quartz, calcite, hematite, pyrite, and chalcopyrite, but nowhere are these constituents concentrated in quantities large enough to form an economic deposit.

Detailed work at Port Radium (Campbell, 1955) showed that the fractures exhibit very pronounced structural differences in various rock types. Generally within the feldspar–hornblende porphyry, granite, massive crystalline tuff, and diabase, the fractures and shear zones are constricted but widen out where they traverse sedimentary rocks of the Echo Bay Group. The greatest amount of dilation takes place within the sediments near the contact with other rock types. Away from the contacts and within the sedimentary strata the veins assume a more uniform width until a new rock formation is encountered. This character of fracturing appears to be dependent on the difference in competency between the two adjacent rock types.

Nearly all mineral occurrences discovered so far are hydrothermal and can be grouped as:

1. Copper
2. Pitchblende
3. Silver
4. Iron gossan.

Copper Occurrences

Evidence of widespread copper mineralization in the area is indicated by numerous small, scattered occurrences of chalcopyrite and green and bright blue copper carbonate stains. Before 1934 many test pits were sunk on these occurrences primarily in search of native silver.

The smaller veins consist of a host of copper minerals with associated quartz, some carbonates, and hematite. The copper-bearing giant quartz stockworks contain small amounts of chalcopyrite, bornite, and covellite, and Kidd (1932, p. 56) reports famatinite from a copper showing near the Sloan River. The quantity of copper minerals in both types of veins is generally small although in some instances copper in giant quartz veins may be of commercial significance. One occurrence of this type is located about 15 miles northeast of Port Radium and has been under investigation by Mariner Mines Limited (Thorpe, 1972).

Pitchblende Occurrences

Like copper, pitchblende mineralization is confined to veins which occupy fractures and shear zones. At Port Radium as well as elsewhere substantial evidence exists that the fractures and shears have been reopened several times and that there were several stages of mineralization. During fracturing the early minerals were brecciated and then cemented by successive mineralizing solutions. Extensive mineralogical studies at Port Radium, conducted by Kidd and Haycock (1935), Campbell (1955), and Jory (1964), indicated that mineralization could be subdivided into five stages, each having a distinct mineral assemblage. As these assemblages and periods may be useful in determining the economics of a deposit they are briefly discussed.

Stage one is represented by deposition of massive, greenish or white quartz and hematite and by a red alteration caused by hematite replacing wall-rocks. Evidence of recurrent movement during this stage is seen from several generations of quartz veinlets which crisscross one another.

Stage two is significant because it encompasses deposition of pitchblende. Brownish grey and creamy quartz are the accompanying products. Both quartz and pitchblende show rhythmic deposition. Towards the end of the second stage, brecciation occurred with subsequent healing by quartz and additional pitchblende.

During stage three quartz and arsenides of cobalt and nickel were the predominant minerals deposited. Quartz from this stage is usually creamy grey and contains fragments of jasper, pitchblende, and brownish quartz from stage two. The quartz material from stage three accounts for the bulk of the vein matter.

Stage four represents a period during which copper sulphides and to a much smaller degree galena, sphalerite, and dolomite were deposited. Quantitatively, chalcopyrite is the most common mineral followed by chalcocite, bornite, and tetrahedrite. Associated with stage four is an extensive introduction of chlorite and clay minerals which appear as veinlets and as replacement of earlier gangue minerals, particularly quartz.

Stage five marks a distinct change from predominantly quartz to carbonate gangue and the deposition of several native minerals. The most common carbonates are dolomite, rhodochrosite, and calcite. Native silver is the main metallic mineral. Indications exist that some chalcopyrite was deposited during this stage and possibly some pitchblende. However, in portions of veins where the carbonates and silver are the dominant constituents, pitchblende is generally not present in quantities sufficiently large to be of economic significance. The paragenetic sequence of mineral deposition is shown in Table V, whereas Table VI lists minerals which were found as surface oxidation products.

It is important to emphasize that at Port Radium, and probably elsewhere, pitchblende deposition is related to stage two and carries quartz as a main gangue mineral. Silver, on the other hand, is one of the last minerals to form and is associated with carbonate gangue. Stages one, two, and four account for the bulk of mineralization at Port Radium and probably throughout the district.

TABLE V *Paragenesis of primary vein minerals at Port Radium (modified from Campbell, 1955)*

Stage	Major minerals	Minor minerals
I Oxides	Quartz, SiO_2 Hematite, Fe_2O_3	Pyrite, FeS_2 Arsenopyrite, FeAsS
	Brecciation	
II Oxides	Quartz, SiO_2 Pitchblende, U_3O_8 Quartz, SiO_2	
	Brecciation	
III Arsenides		Quartz, SiO_2
	Niccolite, NiAs Safflorite–loellingite, $(CoFe)As_2$	Loellingite, $FeAs_2$
	Gersdorffite, NiAsS	Polydymite, Ni_3S_4 Quartz, SiO_2 Smaltite
	Skutterudite, $CoAs_3$	Chloanthite, $(CoNi)As_2$ Glaucodot, (CoFe)AsS Cobaltite, CoAsS Corynite, Ni(AsSb)S Loellingite, $FeAs_2$ Niccolite(?), NiAs
	Brecciation	
IV Copper sulphides (silicates)	Chalcopyrite, $CuFeS_2$	Galena, PbS Sphalerite (marmatite), ZnS(Fe) Stibnite, Sb_2S_3 Molybdenite, MoS_2 Cubanite, $Cu_2S\ Fe_4S_5$
	Chalcocite, Cu_2S	Chalcostibite, $Cu_2S.Sb_2S_3$
	Bornite, Cu_5FeS_4 Montmorillonite Chlorite	(Sericite)
	Tetrahedrite, $5Cu_2S.(CuFe)S.2Sb_2S_3$	Tennantite, $5Cu_2S.(CuFe)S.2As_2S_3$ Chalcocite, Cu_2S Aikinite, $Cu_2S.2PbS.Bi_2S_3$ Covellite, CuS

TABLE V (*Conc.*)

Stage	Major minerals	Minor minerals
	Brecciation	
V Carbonates Silver	Dolomite, $(MgCa)CO_3$ Rhodochrosite, $(MnFe)CO_3$ Quartz, SiO_2 Chalcopyrite, $CuFeS_2$ Bismuth, Bi Argentite (local), Ag_2S Silver (local), Ag	 Hematite, Fe_2O_3 Stromeyerite, $Ag_2S.Cu_2S$ Hessite, Ag_2Te

Substantial evidence exists that, as at Port Radium, many fractures and shears in the district have been reopened several times and that the veins have undergone repeated brecciation followed by deposition of successive minerals. The deposits are either epithermal or mesothermal with marked mineralogical changes downward. At the Port Radium mine economic ore shoots of pitchblende did not extend below a depth of 2,000 feet and mining of silver became uneconomic below 500 feet. At the Echo Bay Mines Ltd., Thorpe (1972) reports economic silver over a vertical interval of some 800 feet. These depths could be adopted as indication for pitchblende and silver deposits in the Port Radium district.

Giant quartz stockworks show evidence of some pitchblende mineralization, but none of the occurrences which are marked on the accompanying map give any promise of being of commercial value. This conclusion is made on the basis of extensive review of published and unpublished data.

TABLE VI | *Secondary minerals found as surface oxidation products (after Campbell, 1955)*

1. Manganese minerals which account for dark coloration:
   (a) Pyrolusite, MnO_2
   (b) Psilomelane, $BaMn^2Mn^4{}_8O_{16}(OH)_4$
   (c) Polianite, MnO_2
2. Copper minerals which account for green and blue coloration:
   (a) Malachite, $CuCO_3Cu(OH)_2$
   (b) Azurite, $2CuCO_3Cu(OH)_2$
3. Uranium minerals which account for yellow and greenish coloration:
   (a) Gummite, hydrated uranyl oxides
   (b) Uranophane, $3UO_3.2SO_3.9H_2O$(?)
   (c) Zippeite, $2UO_3.SO_3.5H_2O$(?)
4. Cobalt and nickel minerals which account for pink and green coloration:
   (a) Erythrite, $Co_3As_2O_8.8H_2O$
   (b) Annabergite, $Ni_3As_2O_8.8H_2O$

Silver Occurrences

Substantial evidence exists that silver is related to the fifth and thus the last stage of mineral deposition. It is associated with carbonate gangue minerals. Pitchblende often accompanies silver but not in quantities sufficiently large to make most of the known prospects commercial. Native silver and argentite are the main silver minerals although smaller quantities of other types may be present. Several properties in the district were developed in the late 1930s but the tonnage was quite small with the exception of the Port Radium mine and the recently reactivated Echo Bay Mines Ltd. As these properties serve as guides for silver mineralization some are briefly described.

Contact Lake Deposits

Two occurrences of pitchblende and silver can be found in the vicinity of Contact Lake, just south of Echo Bay. One lies on a hill about a quarter mile north and about 2½ miles east of the west end of the lake, and the other lies just south of the lake and beyond the map-area. Intermittent testing and development of these properties was done after their discovery in 1931 and 1932 but neither of them proved to contain economic reserves.

North of Contact Lake silver and associated pitchblende occur in a steeply dipping, north-trending vein which measures some 300 feet long. The vein cuts across the contact of granodiorite and what appears to be a younger granite. This relationship is significant because it shows that the mineralization postdates the granite. The vein is up to 6 inches wide and consists of white or grey coarsely crystalline quartz and carbonate minerals. Metallic minerals, which have been identified in the field and from a limited number of polished sections, consist of bornite, chalcopyrite, covellite, specular hematite, pitchblende, native silver, argentite, magnetite, tetrahedrite, stromeyerite, hessite, and a cobalt and nickel mineral (rammelsbergite?). This association of minerals is very similar to that of the Port Radium deposits which would imply that there, too, there might have been five stages of deposition. Silver and pitchblende mineralization is quite spotty and of limited extent; however, when present, silver content could be very high and Kidd (1932d, p. 25C) reports that one channel sample taken across a 4½-inch width assayed as follows: Ag–666.53 troy oz/ton (2,000 lb); U_3O_8–4.31%; Au–none.

The property south of Contact Lake and just south of the Port Radium map-area is of no economic significance but is important in establishing the temporal age of the mineralizing solutions. Here a vein measuring about 100 feet long is found near the centre of what appears to be a diabase dyke, which in turn cuts through a massive, medium-grained granite resembling the late acidic rocks of the district. The vein contains quartz, carbonate, bornite, and some pitchblende and silver. Kidd (1932d, p. 26C) reports the following assay results for a selected sample: Ag–3.92 troy oz/ton (2,000 lb); Au–0.20 troy oz/ton (2,000 lb); U_3O_8–14.15%.

Dowdell Point Deposits

Several pitchblende and silver occurrences known as the Bonanza Group were staked during 1931 at Dowdell Point. The early work consisting of a shallow inclined shaft and some lateral development was done in 1935 and 1936 and some silver concentrates were shipped during those years. The property was closed shortly thereafter but reactivated in 1956–1957 and again in 1965. Drifting resulted in the opening of several small but apparently high-grade ore shoots of silver and Thorpe (1965) estimated that 300 tons of silver ore may have been added to the previous stockpile of about 700 tons.

Kidd (1932a, b) provides an account of the geological setting of the Dowdell Point mineral occurrences which is essentially as follows. Most veins are within a narrow strip of recrystallized and altered volcanic and sedimentary rocks. Lithologically these rocks fit into the Echo Bay Group category. Bordering this strip are granite to the south and granodiorite to the north.

Veins are up to 300 feet long and consist of narrow lacings of quartz and carbonate in shear zones which are up to 30 feet wide. The veins contain sparsely disseminated native silver, chalcopyrite, bornite, galena, hematite, covellite, tetrahedrite, sphalerite, pitchblende, and possibly chalcocite, argentite, and niccolite. Silver minerals are associated with carbonates and occur as blotches or in leaf-like and dendritic structures along cleavage planes of carbonates. Coarsely crystalline carbonates appear to be better hosts for silver than are finely grained types.

Echo Bay Group Deposits

Numerous occurrences of pitchblende and silver can be found on the peninsula between Glacier Lake and LaBine Point. The area is studded with pits and trenches indicating that the ground has been prospected thoroughly and that the possibility of there being any large-scale deposits is not very good. The best mineralized zone, which has recently proved to be economic, is about a mile northeast of LaBine Point. This property was staked by The Consolidated Mining and Smelting Company of Canada Limited in 1930 and tested by trenching and drilling in 1932. Subsequent work led to underground exploration of five mineralized veins by means of two adits at two different elevations. This exploration did not reveal economic ore shoots, but due to increased prices of silver the property became productive in 1964 under the auspices of Echo Bay Mines Ltd. This company attained a production rate of about 100 tons per day of silver ore by the end of 1965. Thorpe (1965) reported a total production for that year of 35,609 tons of ore which yielded 1,408,246 oz of silver or an average of 39.5 oz of silver per ton of ore.

The veins appear to be near the contact between the upper and lower units of the Echo Bay Group within the sequence of volcanic rocks and interbedded sediments. The entire area is marked by heavy gossans due to oxidation of iron oxides and sulphides which are disseminated through the rocks.

The five major veins occupy steeply dipping shear zones and zones of intense fracturing which trend northeast. The largest of the five veins is more than 1,500 feet long. The veins and the mineralization are generally confined to a one-foot-wide section along the central part of the shear zones but may also be present along tight cracks. Kidd (1932a,b,c,d) reported the following minerals from the veins: galena, chalcopyrite, magnetite, pyrite, arsenopyrite, native silver, argentite, pitchblende, and cobalt nickel arsenides. Coarsely crystalline carbonate minerals are relatively abundant in the wider portions of the veins but high-grade sections of silver ore occur irregularly and generally terminate abruptly along strike.

From the mineral occurrence discussion, it becomes clear that in addition to pitchblende and silver a host of other minerals are associated with the veins and that with the proper refining methods it may be possible to obtain byproducts. The nature of these byproducts is shown in Table VIII. This table is based on a four-year production record at Port Radium mine in the late 1950s. The analyses were made on uranium gravity concentrates which contained, in addition to uranium, attractive amounts of copper, cobalt, nickel, lead, and bismuth but a very low concentration of silver. One of the reasons for the low silver content is that, at the time, most of the mining operation was confined to ore shoots below the 500-foot level where silver minerals are sparse or not present.

Iron Gossan Occurrences

There is field and microscopic evidence that considerable amounts of iron were introduced into the country rock by metasomatic solutions emanating from intrusive rocks. Most extensive changes were imposed by solutions coming from the intrusive feldspar–hornblende porphyries and from granodiorite bodies. As discussed in the section dealing with metamorphism and alteration both types appear to be responsible for the introduction of large quantities of iron into the host rock. The iron appears as hematite, magnetite, and pyrite. The last two minerals are concentrated along the borders of the intrusives and, on weathered surfaces, appear as yellow and brown gossans.

TABLE VII *Spectrographic analyses of gossan material–all values in ppm (analyses by G. R. Webber for Eldorado Nuclear Limited)*

	1	2	3	4	5	6	7
B	1,000	3,600	155	525	685	950	112
Ba	>7,000	975	900	500	–	1,700	250
Be	tr	tr	tr	tr	tr	–	tr
Cr	140	137	130	137	195	152	95
Cu	210	132	230	95	175	365	>1,000
Co	16	30	32	30	135	92	17
Ga	tr	tr	tr	tr	tr	tr	tr
Mn	2,400	120	380	<150	4,900	205	>5,000
Mo	<6	7	7	7	18	9	6
Ni	19	16	15	24	68	19	10
Pb	85	11	12	18	45	24	36
Sc	24	34	29	34	45	38	25
Sn	6	8	7	10	17	10	6
Sr	230	57	62	75	137	87	55
Ti	2,700	3,350	2,550	3,000	3,050	4,900	3,300
V	125	200	140	185	215	220	192
Y	15	16	15	18	27	36	14
Zn	tr	tr	tr	tr	90	tr	tr
Zr	152	150	147	165	180	100	60
Ag	tr	5	tr	6	tr		tr

The samples are composites and the numbers correspond to the following localities:

1. Gossan Island
2. Gossan west of Cleaver Lake
3. Gossan ½ mile northwest of Cleaver Lake
4. Gossan at the southwest end of Glacier Lake
5. Gossan at the northeast end of Glacier Lake
6. Gossan ½ mile west of Sparkplug Lake
7. Gossan at the south end of Stevens Island

TABLE VIII *Average spectrographic analyses of uranium gravity concentrates from Port Radium mine—all values in %*

U	13.81	Pb	2.56	Mo	0.05
Fe	10.8	P	0.88	Na	.03
Si	10.2	Mn	.7	Gd	.029
As	8.5	Bi	.68	B	.02
Cu	4.8	Ti	.14	Be	tr
Co	4.6	Sb	.12	Cd	tr
Ca	3.4	Y	.11	Cr	tr
Mg	3.2	Ag	.09	Sn	tr
Al	2.9	V	.09	Zn	tr
Ni	2.9	Dy	.052	Zr	tr

Data based on a four-year production record.
Analyses courtesy of Eldorado Nuclear Limited.

During the early days of exploration some trenching was done on the gossans in anticipation that they might contain valuable metals, but none seem to have been discovered. To test the possibility further the writer collected grab samples from all major gossans. Spectrographic analyses of these samples (Table VII) do not show any quantities of metals that could be considered economic. The concentrations of most elements are not much higher than one would expect to encounter in some igneous rocks from the Port Radium district (Table IX).

TABLE IX *Spectrographic analyses of rock samples from Port Radium district—all values in ppm (analyses by G. R. Webber for Eldorado Nuclear Limited)*

	Intrusive Rocks					Volcanics from upper unit of Echo Bay	
	Granite	Quartz monzonite	Grano-diorite	Feldspar–hornblende porphyry	Diabase	Dacite	Andesite
B	57	138	90	65	39	46	77
Ba	2,343	2,183	2,550	1,612	1,700	2,687	1,990
Be	4	6	<4	4	–	2	4
Cr	149	133	178	151	260	139	163
Cu	37	41	43	64	140	33	25
Co	23	20	36	27	52	46	32
Ga	<38	85	<42	22	tr	tr	tr
Mn	>3,210	2,233	>3,950	>3,500	3,800	1,250	>4,230
Mo	9	9	10	10	13	8	9
Ni	26	16	37	22	90	15	21
Pb	16	70	67	57	tr	tr	40
Sc	26	26	35	30	49	28	33
Sn	10	12	10	11	12	10	10
Sr	200	270	305	241	235	185	228
Ti	<3,320	3,750	3,962	3,566	3,900	2,850	3,560

TABLE IX (*Conc.*) *Spectrographic analyses of rock samples from Port Radium district—all values in ppm (analyses by G. R. Webber for Eldorado Nuclear Limited)*

	Intrusive Rocks					Volcanics from upper unit of Echo Bay	
	Granite	Quartz monzonite	Grano-diorite	Feldspar-hornblende porphyry	Diabase	Dacite	Andesite
V	119	<102	186	190	255	110	151
Y	30	58	37	30	27	18	29
Zn	tr	0	400	192	tr	tr	166
Zr	243	285	251	154	107	134	150
Number of samples	4	3	4	6	1	2	6

In addition to the elements shown, the samples were also tested for As, Cd, Ge, Hg, Li, Nb, Sb, Ta, Th, U, and W, but none of these elements were detected by the methods employed. It should be pointed out that the spectrographic techniques were semiquantitative and that the precision varied with the element but averaged between 9 and 50 per cent.

Origin of Pitchblende

Much has been written on the origin of pitchblende and on the source of the mineralizing solutions in the Port Radium district. Almost every individual mentioned in the section entitled "Previous Work" has touched on the subject.

From a structural standpoint it is quite clear that the system of fractures and shears which are occupied by mineralized veins developed after consolidation of all major intrusive bodies. This would preclude the possibility that they were the sources of metals.

Radiometric age dates at Port Radium indicate an age for the granite of approximately 1,800 m.y. (Jory, 1964) and for pitchblende about 1,400 m.y. (Campbell, 1955). Campbell, however, provides a lucid account by which he illustrates that the 1,400 m.y. dates may be much too old and may be due to leaching of radium from pitchblende by later hydrothermal solutions. This view may be strengthened even further if one considers the ages of pitchblende from Hottah Lake, some 40 miles south of Port Radium, where the pitchblende was dated at about 580 m.y. by the University of Toronto in 1952 (Collins *et al.*, 1952).

Diabase dykes which occupy the fault and shear zones are the only major rock types which postdate the period of fracturing but in a number of cases the dykes themselves are fractured and healed by vein materials. On a regional scale diabase dykes in the Bear Province[1], which encompasses Port Radium district, show an age of 875 m.y. (Fahrig and Wanless, 1963).

[1] Unofficial local name.

It is emphasized by some authors (McKelvey *et al.*, 1955; Kerr, 1958) that uranium is normally derived from acidic magma whereas other writers (Gottfried, 1959; Page, 1960) give indications that basic rocks are capable of supplying the needed material. In the Port Radium district diabase dykes are not sufficiently large to account for the extent of mineralization unless subjacent magma of basaltic composition was responsible for mineralizing fluids.[1]

[1] Since this MS. was submitted Badham *et al.* (1972) report that the metalliferous components of the ore deposits originated within the Echo Bay volcanics and were probably transported by brines into the fracture zones at a depositional thermal maximum of 230°C.

REFERENCES

Anderson, E. M.

1951: The dynamics of faulting and dyke formation with applications to Britain; London, Oliver and Boyd, 2nd ed. (revised), 206 p.

Badham, J. P. N., Robinson, B. W., and Morton, R. D.

1972: The geology and genesis of the Great Bear Lake silver deposits; Rept. 24th Sess. Can., Int. Geol. Congr., sect. 4, p. 541–548.

Bailey, E. H. and Stevens, R. E.

1960: Selective staining of K-feldspar and plagioclase on rock slabs and thin sections; Amer. Mineral., v. 45, p. 1020–1025.

Bateman, J. D. and Jolliffe, A. W.

1944: Map of Eldorado mine area; Geol. Surv. Can., Spec. Map.

Bell, J. M.

1901: Mackenzie District; Geol. Surv. Can., Sum. Rept. 1900, pt. A, p. 95–103.

Campbell, D. D.

1955: Geology of the pitchblende deposits of Port Radium, Great Bear Lake, N.W.T.; unpubl. Ph.D. thesis, Calif. Inst. Technol., 323 p.

Collins, C. B., Lang, A. H., Robinson, S. C., and Farquhar, R. M.

1952: Age determinations for some uranium deposits in the Canadian Shield; Proc. Geol. Assoc. Can., v. 5, p. 30.

Fahrig, W. F. and Wanless, R. K.

1963: Age and significance of diabase dyke swarms of the Canadian Shield; Nature, v. 200, No. 4910, p. 934–937.

Feniak, M.

1947: The geology of Dowdell Peninsula, Great Bear Lake, N.W.T.; Geol. Surv. Can., Spec. Rept., 29 p.

1952: MacAlpine Channel, Great Bear Lake, Northwest Territories; Geol. Surv. Can., Map 1011A (with descriptive notes).

Fortier, Y. O.

1948: Geology of Glacier Lake areas, Great Bear Lake, Northwest Territories; Geol. Surv. Can., Spec. Rept., 9 p.

Fraser, J. A.

1960: North–Central District of Mackenzie; Geol. Surv. Can., Prel. Series Map 18–1960 (with descriptive notes).

Furnival, G. M.

1935: The large quartz veins of Great Bear Lake, Canada; Econ. Geol., v. 30, p. 843–850.

1939: Geology of area north of Contact Lake, N.W.T.; Amer. J. Sci., v. 237, p. 478–479.

Godfrey, J. D.
1958: Aerial photographic interpretation of Precambrian structures north of Lake Athabasca, Alberta; Res. Council, Alberta, Geol. Div., Bull. 1, 19 p.

Gottfried, D.
1959: Distribution of uranium in igneous complexes; *in* Geologic investigations of radioactive deposits; Semiann. Progr. Rept. for Dec. 1, 1958 to May 31, 1959, U.S. Geol. Surv. Trace Element Invest. Rept. TEI-751, p. 102–110.

Griffith, J. W.
1956: A bibliography on the occurrence of uranium in Canada and related subjects; Geol. Surv. Can., Paper 56-5, 34 p.

Jolliffe, A. W. and Bateman, J. D.
1944: Map of Eldorado map-area; Geol. Surv. Can., Spec. Map.

Jory, L. T.
1964: Mineralogical and isotopic relations in the Port Radium pitchblende deposit, Great Bear Lake, Canada; unpubl. Ph.D. thesis, Calif. Inst. Technol., 275 p.

Kerr, P. F.
1958: Uranium emplacement in the Colorado Plateau; Bull. Geol. Soc. Amer., v. 69, p. 1075–1112.

Kidd, D. F.
1932a: Great Bear Lake–Coppermine River area, Mackenzie District, N.W.T.; Geol. Surv. Can., Sum. Rept., 1931, pt. C.
1932b: Geology and mineral deposits of Great Bear Lake–Coppermine District; Bull. Can. Inst. Mining Met., v. 245, p. 512–523.
1932c: A pitchblende–silver deposit, Great Bear Lake, Canada; Econ. Geol., v. 27, no. 2, p. 145.
1932d: Great Bear Lake area, N.W.T., Geol. Surv. Can., Sum. Rept., 1932, pt. C. (publ., 1933).

Kidd, D. F. and Haycock, M. H.
1935: Mineragraphy of the ores of Great Bear Lake; Bull. Geol. Soc. Amer., v. 46, p. 879–960.

Lord, C. S.
1952: Camsell River 86F, District of Mackenzie; Geol. Surv. Can., Map 1014A.

McKelvey, V. E., Everhart, D. L., and Garrels, R. M.
1955: Origin of uranium deposits; Econ. Geol. 50th Anniversary Vol. 1905–1955, pt. 1, p. 464–533.

McKinstry, H. E.
1953: Shears of the second order; Amer. J. Sci., v. 251, p. 401–414.

Mursky, G.
1963: Mineralogy, petrology and geochemistry of Hunter Bay area, Great Bear Lake, N.W.T., Canada; unpubl. Ph.D. thesis, Stanford Univ., 144 p.

Page, L. R.
1960: The source of uranium in ore deposits; Rept. of the 21st Sess. Norden, Int. Geol. Congr., pt. 15, p. 149–164.

Parsons, W. H.
1948: Camsell River map-area, Northwest Territories; Geol. Surv. Can., Paper 48-19, 12 p.

Ridge, J. D.
1958: Selected bibliographies of hydrothermal and magmatic mineral deposits; Geol. Soc. Amer., Mem. 75, p. 15–16.

Riley, C.
1935: The granite-porphyries of Great Bear Lake, N.W.T., Canada; J. Geol., v. 43, p. 497–525.

Robinson, H. S.
1933: Notes on the Echo Bay District, Great Bear Lake, N.W.T.; Bull. Can. Inst. Mining Met., no. 258, p. 609–628.

Thorpe, R. I.
1965: Mineral industry of the Northwest Territories; Geol. Surv. Can., Paper 66-52, 66 p.
1972: Exploration and mining 1966 to 1968 mainland Northwest Territories (excluding the Coppermine River area); Geol. Surv. Can., Paper 70-70.

Thurber, J. B.
1946: Glacier Bay-Cameron Bay area, Great Bear Lake, N.W.T.; Geol. Surv. Can., Spec. Rept., 9 p.

Wilson, J. T.
1948: Some aspects of geophysics in Canada with special reference to structural research in the Canadian Shield (Part 2. An approach to the structure of the Canadian Shield); Amer. Geophys. Union Trans., v. 29, p. 691–726.