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GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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R. H. Ridler and W. W. Shilts

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CONTENTS

Illustrations

Page

ABSTRACT

Pilot stratigraphic/metallogenic studies of Archean bedrock and drift prospecting in permanently frozen terrain have provided integrated models for exploration in the Rankin Inlet-Ennadai Belt. Techniques perfected during both studies have provided data that allow effective differentiation of target areas for follow-up exploration.

The geological environment in the vicinity of Kaminak Lake is similar to that of the Noranda area. An extensive platform of basalt and andesite flows is overlain by andesitic to rhyolitic pyroclastic units intruded by coeval plutonic rocks. An exhalite zone of regional extent is present in the felsic unit. A centre of felsic accumulation with a proximal exhalite zone possessing local enrichments in base and precious metals occurs at Spi Lake.

Because the <2 micron fraction is common to all till samples and because it is thought to have scavenged metal cations released by the weathering of sulphides that were glacially eroded and included in till, it was chosen as the most effective fraction to analyze. Maps of Cu and Zn distribution, drawn from results of <2 micron analyses, confirm the presence of known exhalite zones and allow the zones to be traced through areas of persistent drift cover. Analyses of other fractions (methylene iodide separates, heavy rock fragments, <250 mesh) give less reliable but sometimes corroborating results.

RÉSUMÉ

Des études pilotes stratigraphiques et métallogéniques de la roche en place archéenne et la prospection de matériaux glaciaites dans le pergélisol ont fourni des modèles intégrés d'exploration dans la zone de Rankin Inlet-Ennadai. Les techniques mises au point au cours de ces études ont fourni des données qui permettent la différenciation efficace des régions cibles pour explorations subséquentes.

L'environnement géologique dans le voisinage du lac Kaminak est semblable à celui de la région de Noranda. Une vaste plate-forme de couleés de basalte et d'andésite est recouverte d'unites pyroclastiques andésitiques et rhyolitiques avec intrusions de roches plutoniques de même âge. On retrouve dans toute la région une zone d'exhalite dans l'unité felsique. On rencontre au lac Spi une accumulation de matériaux felsiques ainsi qu'une zone voisine d'exhalite riche en métaux précieux et communs.

On a choisi la fraction <2 microns comme étant la plus apte à une analyse exacte parce qu'elle est commune à tous les échantillons de till et parce qu'on croit qu'elle contient des cations de métal évacués par l'altération des sulphures qui ont été érodés par la glace et incorporés au till. Des cartes de répartition du Cu et du Zn, établies d'après les résultats obtenus par des analyses de la fraction <2 microns confirment la présence de zones connues d'exhalite et permettent de tracer ces zones dans des régions recouvertes de matériaux glaciaites. Des analyses d'autres fractions (particules séparées d'iodure de méthylène, lourds fragments de roches, <250 mailles) sont moins sûres mais confirment parfois ces résultats.

EXPLORATION FOR ARCHEAN POLYMETALLIC SULPHIDE DEPOSITS IN PERMAFROST TERRAINS: AN INTEGRATED GEOLOGICAL/GEOCHEMICAL TECHNIQUE; KAMINAK LAKE AREA, DISTRICT OF KEEWATIN

INTRODUCTION

During the past fifteen years a great deal of thought and research has been devoted to understanding the nature and origin of stratabound sulphide masses (Sangster, 1972; Hutchinson et al., 1971; Goodwin, 1965; Stanton, 1960; Roscoe, 1965; Kalliokoski, 1965; Vokes, 1969; Gilmour, 1965; Lusk, 1969; Tatsumi,1970). Considerable evidence supports an interpretation that the sulphides are coeval with their host rocks. In the case of volcanic rocks the close spatial relationship of sulphide zones to calc-alkaline felsic volcanics, and the common presence of alteration zones stratigraphically under the sulphide zones has lead to the additional conclusion that the felsic volcanics and sulphides are cogenetic. Ridler (1970, 1971a) and Hutchinson et al. (1971) proposed an integration of the various types of volcanogenic chemical sediments, including sulphide, under the exhalite model. In this model, exhalites are the class of chemical sediments of predominantly volcanic exhalative origin and may be classified as to their geological relations (Fig. 1) or chemical composition (Fig. 2).

Two empirical characteristics of the target, polymetallic sulphide facies, are useful in exploration: 1) the tendency of sulphide facies to be correlative on a regional scale with carbonate and oxide facies exhalite and 2) the tendency of the sulphide facies to occupy one or two principal stratigraphic levels within felsic volcanic sequences.

The exhalite zone is relatively easy to find. On the other hand, the specific targets, proximal sulphide orebodies, have characteristics that make them difficult to find. Their usual geometry is that of a greatly thickened convex lens (up to a few hundred feet thick by several hundred to a thousand feet in diameter) scattered in an exhalite zone which might average only a few inches to a few feet in thickness over the intervening miles. The geochemical "halo" associated with these proximal lenses is usually confined to the underlying alteration zone and the immediately adjacent distal exhalite zone. While oxide and siliceous carbonate exhalite tend to outcrop well, the sulphide facies and its host felsic volcanics commonly occupy topographic depressions.

The exploration methods must 1) establish a favourable volcanic environment 2) establish the presence of favourable facies zonation and major exhalite zones, 3) isolate felsic volcanic formations and their effusive centres, within the favourable facies zone, 4) using detailed stratigraphy and correlation, isolate the position of a main exhalite zone within the felsic formation, and 5) (assuming limited outcrop), use some geophysical or geochemical technique to find the proximal lenses.

Isolation or even recognition of major portions of the main exhalite zone is a problem, even with abundant outcrop. The fundamental reason is that in the universally folded (and refolded) Archean, exhalite zones are often the loci of much of the consequent strain release. Most exhalites are thus deformed, translated, recrystallized and dismembered more than their enclosing rocks. In addition, there is a traditional tendency to view all rocks of exotic mineralogy as epigenetic. Furthermore, iron-poor species of

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exhalite have had no group name by which to classify them. Thus, maps more than a few years old and many modern maps indicate many of the carbonate, sulphide or silicate varieties, particularly in the absence of layering, as shear zones, veins, or altered rock. Moreover, many exhalite zones are too thin, without cartographic exaggeration, to be shown on conventional geological maps.

Although geochemical drift prospecting has been used to locate economic mineralization in Scandinavian countries, relatively little research has been carried out in Canada and most investigations have been concentrated in areas south of the limit of continuous permafrost. Although it is possible that some form of drift prospecting has been carried out in permanently frozen terrain in Russia, Russian literature is generally not readily accessible in Canada. Apart from a pioneering attempt by Hornbrook and Allan (1970), this paper and companion reports are thought to represent the first results of a geochemical drift-prospecting program designed specifically for permanently frozen terrain. Because of chemical and physical processes that are unique to the active (seasonally thawed) zone, new approaches in sample collecting and processing were required if expensive and logistically difficult overburden drilling through permanently frozen sediment was to be avoided.

Shilts (1973) has described the general nature of physical and chemical processes that significantly influence trace-element geochemistry of glacial sediments in permanently frozen terrain. The important conclusions from that study were:

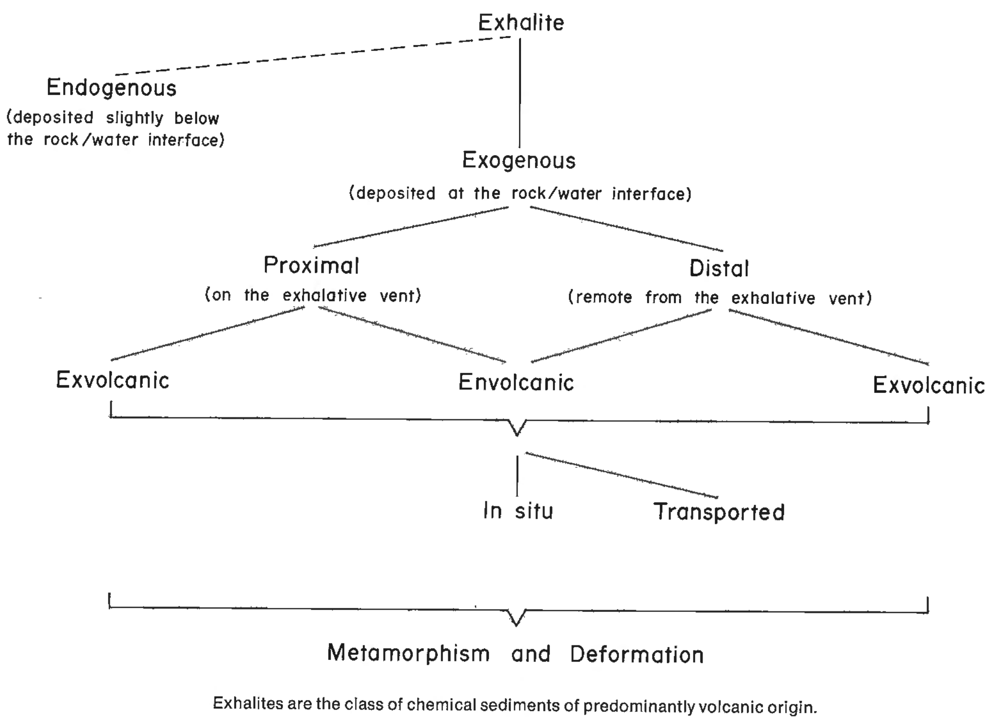

Figure 1. Geological classification of exhalite.

1) primary sulphide particles, eroded from mineralized sources and spread out in indicator trains, persist unaltered only in the permanently frozen sediment and are largely destroyed by intense chemical weathering in the active zone.
2) secondary weathering products (Fe and Mn oxides) and clay-size particles of primary (glacial abrasion) or secondary (weathering) origin are preferentially removed by surface run-off from the active zone on till and marine sediment because of the overturn caused by mud boiling. On the other hand, these products are largely retained within the profiles developed on well-sorted, sandy-gravelly sediments; and
3) the clay-size fraction that is not removed from the till has cation exchange capacity and can scavenge cations released by decomposition of the glacially transported sulphides. Thus, the clay-size fraction (0.3 to 2μ) of tills was found to give the best approximation of original cation concentration and was recommended for routine analysis of till samples collected from the active zone.

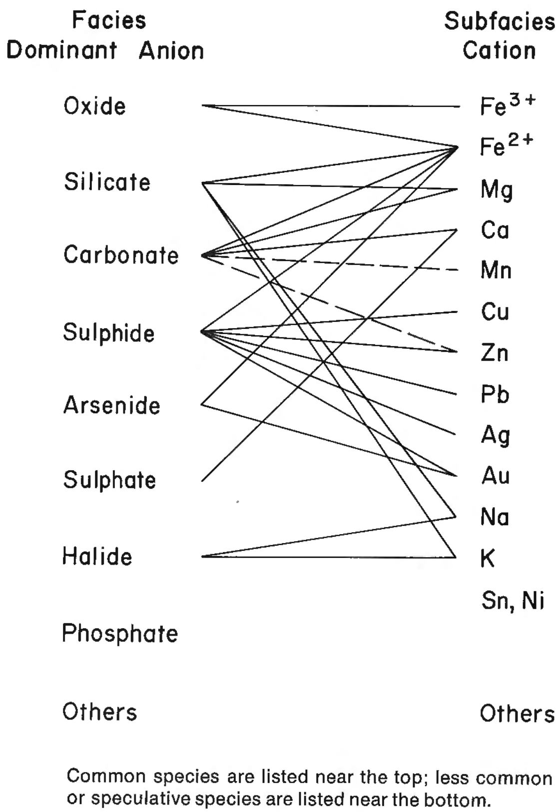

Figure 2. Chemical classification of exhalite.

In this paper, maps drawn from the results of clay analyses are considered the most useful, but comparable maps drawn from analyses of other fractions of the same samples are also presented for comparison.

Acknowledgments

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METHODS

Sampling and Analyzing Bedrock

Introduction

Stratigraphic and metallogenic work in the Kaminak Group (Davidson, 1970a) took place over the course of three summers (average summer = 9 weeks) from base camps established at northern Quartzite Lake (1970), Last Lake (1971) and Turquetil Lake (1972)(Fig. 3). Several temporary and/or fly camps were also utilized.

During this time six major cross-sections of the Kaminak Group volcanics were examined and sampled in detail (Ridler, 1971b, 1972, 1973). Other samples were collected at various sites remote from the major cross-sections. Approximately 400 chip samples of Archean volcanics were obtained for bulk-oxide analysis.

During the same period, more than 150 sites of metallogenic interest were examined and sampled, the majority being various types of exhalite. About two hundred specimens have been analyzed for gold and silver.

Several areas of structural or stratigraphic interest were examined in order to interpolate the formations revealed by the study of detailed sections.

Stratigraphy

The method used in examining the volcanic stratigraphy is directly derived from Goodwin (1970) and adapted for tundra conditions. Stratigraphic units are examined and sampled for chemical analysis in such detail that, ideally, no significant rock type is missed. Thus, cross-sections are picked to maximize recovery of pertinent information. To do this the following are required:

a) minimum standard of geological information must be a map at a scale of 1:250,000
b) location of greatest thickness of volcanics

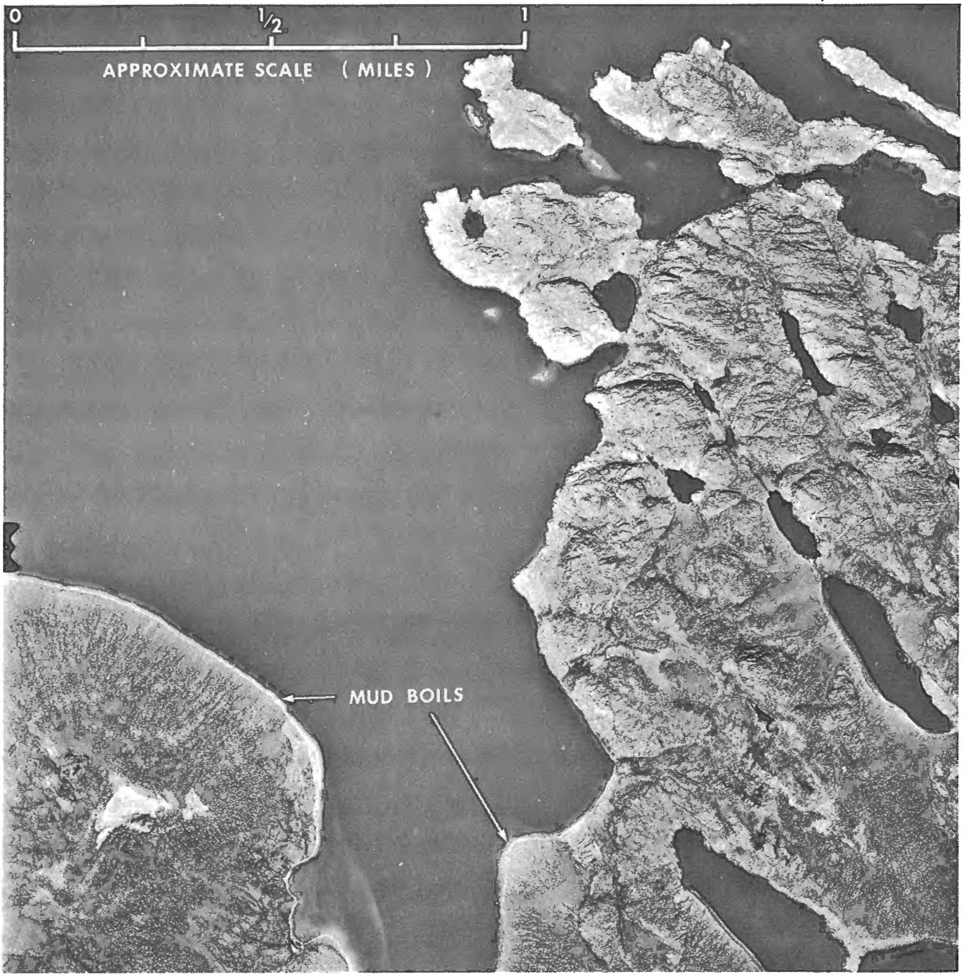


Figure 5. Aerial view of the east-central part of Carr Lake. Note contrast between area of extensive outcrop (northeast corner) and area of complete drift cover (southwest corner). Small light dots in drift area are mud boils. (Photo No. A19396-157).

c) greatest variety of lithologies, (b and c usually coincide)
d) maximum area of unweathered outcrop
e) lowest metamorphic/deformation intensity
f) best access, considering cost, travel time, etc.

The abundant, glacially scoured outcrop that occurs in a wide, gentle arc from Spi Lake through Quartzite Lake to Wilson Bay probably exceeds in quality and continuity any other Archean terrane in the world (Fig. 5). Normally recessive rock types such as interflow black shales, sulphide and carbonate bodies, sericitic and chloritic "paper schists", and soapstone can be found in outcrop. Contacts are exposed at many localities.

The generally low degree of metamorphism and deformation has permitted preservation of many primary "top" indicators. Areas of tens of square miles have outcrop in excess of 70 per cent. Thus, the Kaminak Group is ideally displayed for study.

Two extreme cases put limits on sampling density. If the lithology is uniform, samples are taken at regular intervals of about 1,500 feet. If the lithology is highly varied, all visually obvious varieties are sampled, or more samples are taken at irregular intervals (of about 700-900 feet). The first case applies particularly to the thick "plates" of intermediate to mafic flows, the second to heterogeneous felsic "piles". In the vicinity of and between sample points all of the exposures are studied, particularly for "top" indicators. The abundance of pillow lava and the widespread rock exposure have insured excellent sense-of-younging control.

Samples are taken at right angles to the bedding. Chips are obtained by sledge hammer at, as few as one, but usually 4 or 5 spots. Sample width varies from a point (rare) to 200 feet. Average sample width is 30-50 feet. Two to five pounds of chips are collected. Weathered material, intrusions, and large veins are avoided.

Some rocks, such as flow tops and thin interflow tuffs, tend to become highly foliated or "sheared" during greenschist metamorphism and deformation. Since this recrystallization represents predominantly textural rather than compositional change, such rocks are sampled. Otherwise rocks of obvious compositional interest would be systematically eliminated. In the Rankin Inlet-Ennadai Belt the extensive outcrop and lack of vegetation present an ideal opportunity to sample such rocks which typically occupy topographic depressions.

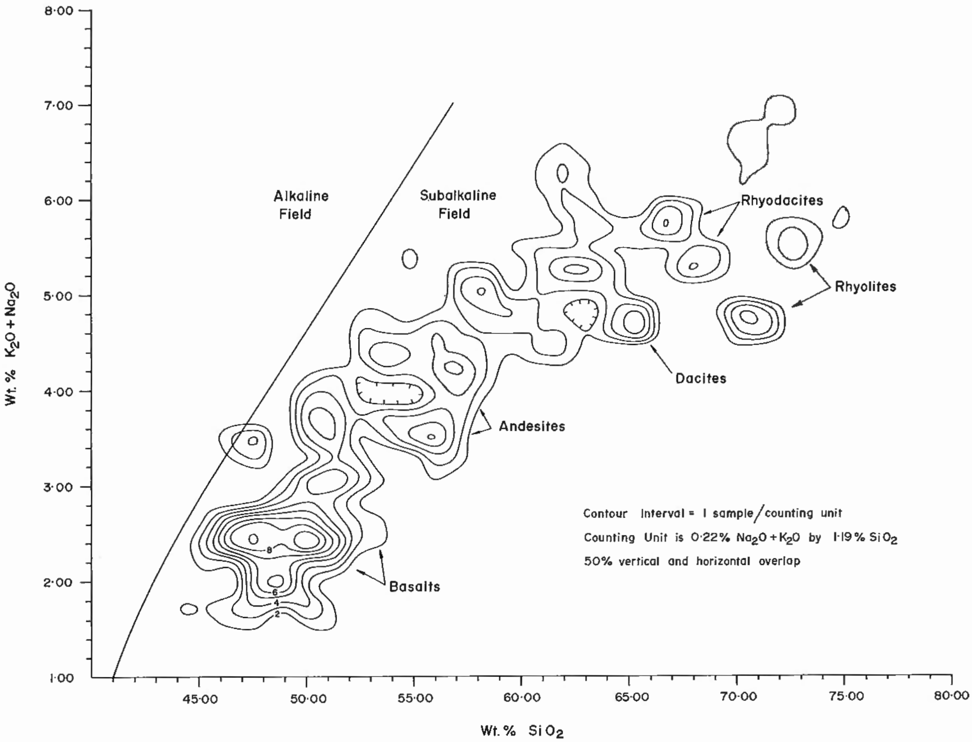
Standard "Rapid Methods" of chemical analysis of the Geological Survey were employed (Maxwell, 1968) to determine thirteen oxides (Table I). The method is an XRF technique supported by standard wet chemical techniques. It is believed that error limits inherent in the above method are consistent with or less than errors inherent in the field sampling technique and that, when used in comparison with hundreds of similarly derived compositions, form a basis for identification of the various volcanic rock types (Fig. 6).

Metallogeny

Several metallogenic types were sought and examined during the course of the project but the emphasis was on exhalite. Three factors determined this course:

1) Exhalites are the principal value-producing metallogenic type in the Archean (i. e. polymetallic massive sulphides, auriferous pyritic carbonate, and iron-formation).
2) The principal zones are usually found while doing detailed volcanic stratigraphy in areas of continuous outcrop.
3) Exhalite, particularly the oxide facies, is often expressed as anomalous, curvi-linear highs on conventional aeromagnetic maps, making the zones relatively easy to find and trace out.

Prospecting activity (Laporte (1972), Thorpe (1972)) and mapping by the Geological Survey has recorded some of the larger gossans in the area and several mineral occurrences. These findings are published or available



Analyses have been adjusted for excess volatile content in the following manner: if $H_2O + CO_2 > 7\%$ and $SiO_2 > 59\%$, volatiles reduced to 2.8% and balance prorated; for $SiO_2 < 59\%$ volatiles reduced to 3.3% and balance prorated. Dividing line after Irvine and Baragar (1971).

Figure 6. Contoured variation diagram of $K_2O + Na_2O$ versus SiO_2 for various volcanic rock types of the Kaminak Lake area (199 samples).

in files and are convenient targets for metallogenic examination. Other than simple quartz veins, most of the discoveries are varieties of relatively sulphide-rich exhalite or related phenomena (Fig. 1). In addition, previous work (Ridler, 1970) suggests that exhalite zones of proven economic worth will have anomalous values in precious metals in not only their proximal but also their distal portions.

The implication of the second point above is that a detailed cross-section in an area of heavy outcrop, chosen for reasons outlined previously, should intersect any formation of regional extent. Major exhalite zones vary greatly in thickness, composition (Fig. 2) geometry, and texture and may even transgress major lithofacies contacts (Goodwin and Schlanka, 1967) or unconformities (Ridler, 1970), but they tend to persist throughout a basin (Goodwin and Ridler, 1970; Ridler, 1971a, 1973). Exhalite is thus a characteristic though volumetrically insignificant rock type in Archean greenstone belts.

The third point above is critical. Oxide facies exhalite is easy to find and may be followed along strike to the facies boundaries. Exhalites are characteristically a mixture of compositions, although one predominates in any one facies zone. This characteristic insures the presence of enough magnetite (or magnetic pyrrhotite) at intervals in the non-oxide facies to produce local, albeit weak anomalies, which are sufficient to draw attention (Fig. 8).

At individual sites a suite of hand samples was selected to represent variations in composition and texture. Each locality was classified in the field as to facies and relation to host rocks. Host rocks were sampled occasionally. Primary and tectonic textures were recorded and thicknesses were measured wherever possible. Three localities became the foci of student thesis (Vaivada, 1972; Venskus, 1973; Bowen, in preparation).

In addition to standard thin and polished section examination, about 200 specimens were analyzed for gold and silver; about half of these from the Spi Lake area (Table II). Specimens were selected to give areal coverage, to test the distribution of precious metals between various compositional types of exhalite, and to establish background. Thus, multiple samples from one specimen, or from one site have been analyzed.

The analytical method employed for gold was a combined fire assay-atomic absorption technique and that for silver, hot HNO_3-HCl extraction and atomic absorption. The method for gold is precise and accurate enough given the great natural range expected (0-20,000 p.p.b.), the nature of the sampling technique, and the vagaries of natural distribution. The actual error limits are: 5-100 p.p.b. gold, one relative standard deviation is 21.6%: more than 100 p.p.b. gold, one relative standard deviation is 10.2%.

Sampling and Analyzing Glacial Sediments

During the summer of 1971 sample grids were completed over the north arm of Kaminak Lake and over the Carr Lake-Spi Lake areas (Fig. 12). Samples were collected approximately on one-mile centres except in the vicinity of the massive sulphide showing at Spi Lake where nine additional samples were collected within a two-mile radius of the showing. The locations of the sample grids were chosen to include areas underlain by felsic volcanic formations overlying the Kaminak Batholith as well as portions of the batholith itself. Known areas of base-metal mineralization, areas of contrasting drift thickness and texture, and areas of heavy marine cover are included within the grids.

Sampling procedures and analytical methods are described fully in a companion paper (Shilts, 1973), and are summarized briefly here.

The sampled materials were poorly sorted till and, rarely, silty clayey marine sediments. Because of considerations discussed previously (Shilts, 1973) mud boils form exclusively on these types of sediments. A mud boil was excavated at each site to a depth of 30 to 60 cm to provide a sample. Mud boils are diapiric structures and diapirs composed of wet, red, plastic till were sought wherever possible (Figs. 10, 11). Hard, sandy carapace was sampled at sites where boils were stable and no diapirs could be found.

Two size fractions were separated from all samples, and two additional fractions were separated from selected samples. Three other fractions were derived from selected samples (Fig. 9, Table III) but were not contoured. The four fractions for which data are contoured are:

1) -250 mesh: material finer than 250-mesh (about 64μ) size was sieved from dried, disaggregated samples. The total sample was not crushed to homogeneity. Only particles originally finer than 250-mesh were analyzed.

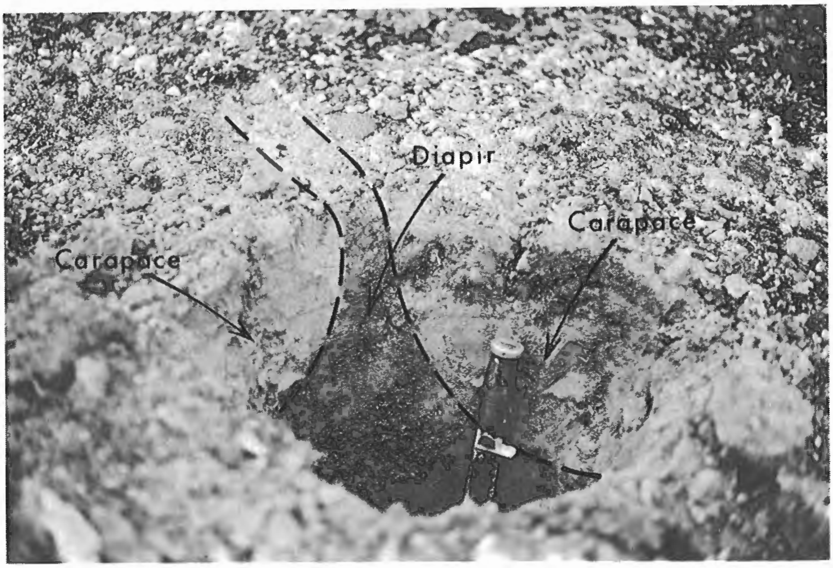


Figure 10. Diapir of plastic till intruding grey, non-plastic carapace. Excavation is in active mud boil north of Kaminak Lake. Dashed lines outline intrusion and its surface trace. The diapir is a dyke-like intrusion over 4 feet long and its surface is coated by white salts of unknown composition. (GSC-201696O)

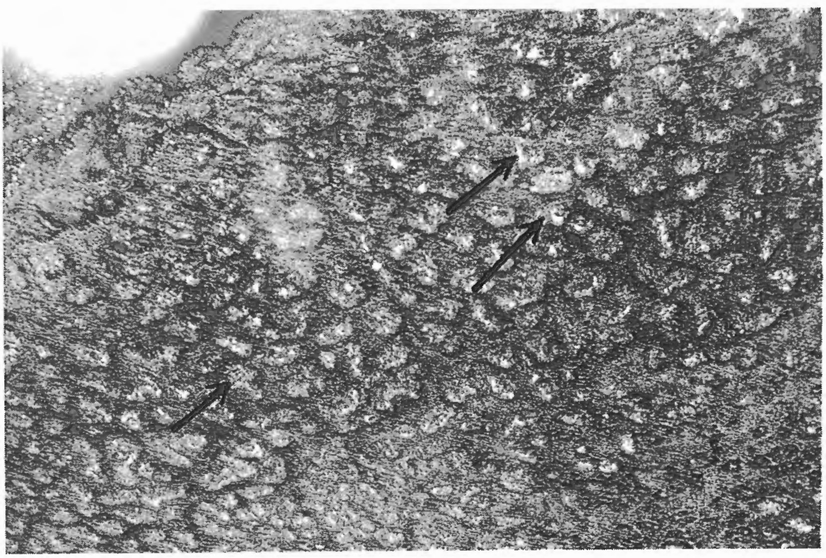


Figure 11. Aerial view of active mud boils from altitude of about 300 feet. Boils average 3 to 5 feet in diameter. Light spots at tips of arrows are freshly extruded diapirs. Faint linear features that run left to right are Caribou trails. (GSC-201696V)

2) Clay: material finer than 2μ was centrifuged from dry-sieved, -250-mesh material from all samples. Centrifugation before total drying of the sample produced slightly higher trace-element values. Centrifugation at high R. P. M. allowed aggregates of particles of 0.3μ to 2μ diameter to be collected, dried and crushed to a powder in a ballmill.
3) Methylene Iodide "heavy minerals": sand-sized minerals heavier than 3.3 specific gravity were separated in methylene iodide. Magnetic grains were removed from the separate and the remaining grains were crushed to -250 mesh with an agate mortar and pestle. Only selected samples were chosen for this analysis.
4) Heavy Rock Fragments: Polymineralic (rock) fragments of 0.25 to 1.0 mm diameter and specific gravity $\gtrsim$2.85 were separated in bromoform and crushed in an alumina-ceramic ballmill to -250 mesh. Only the Carr Lake grid samples were analyzed in this fashion.

All of the above separates were analyzed by atomic absorption after a two-hour, hot, HCl-HNO_3 leach. Elements analyzed were Cu, Zn, Pb, Ni, Co, and Ag. Only Cu and Zn results are reported here, but other results will be made available later.

Data were plotted using the Symap program with typewriter output. These maps were redrafted at an appropriate scale on a simplified geological base map. No averaging or other statistical manipulation was employed. Selected elements were plotted in "topographic" perspective, mainly to enhance visual conception of the anomalies (Fig. 13).

Approximate costs and details of sampling, analyses, and data processing are available from the authors on request.

In order to construct and interpret maps that accurately outline areas of metal-rich drift, several assumptions have been made after careful inspection of trace-element data, descriptive field data, and mineralogy of samples and bedrock sources. The validity of most of the assumptions may be confirmed by reference to Figures 9 and 14.

1) The primary assumption is that potential ore-grade Cu-Zn mineralization will be in the form of massive sulphides or other mineral concentrations of high specific gravity.
2) Indicator trains of sulphide-bearing fragments and sulphide minerals were formed during glaciation and are probably preserved in unweathered till. Such trains are well developed in unweathered till sampled by deep overburden drilling in the Timmins-Noranda area (Skinner, 1972), and the second author has observed them in southeastern Quebec. Strong indicator trains of Dubawnt Group erratics from sources up to 80 miles west of Kaminak Lake and a 16-mile-long garnet train trailing southeast from an alkaline intrusion on Kaminak Lake (Fig. 4) suggest that good, southeastward glacial dispersal of mineralized fragments can be expected in the study area.
3) Sulphide grains and sulphides in rock fragments are largely destroyed by weathering in the active zone that is developed on glacial sediments in the region (Fig. 9). Therefore, not only are primary sulphide particles likely to be absent within one metre of the surface, but also, because the frost table was at

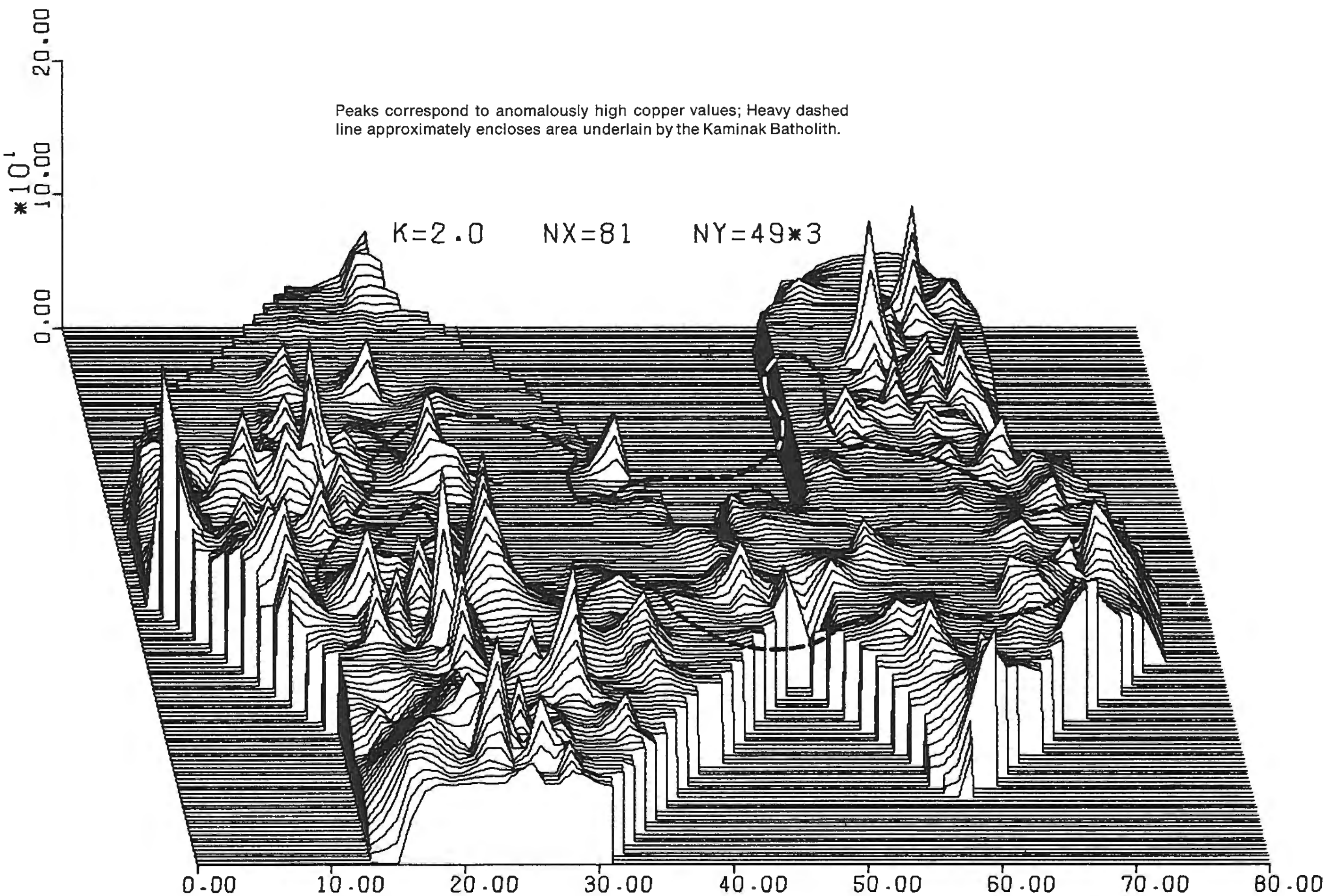


Figure 13. Perspective view of copper anomalies in clay samples, Spi Lake area.

one time at least one metre below the modern permafrost table, sulphides may also be largely destroyed in the upper metre of presently frozen sediment.

4) Some components associated with disturbed till in the active zone have served as scavengers of cations released by weathering of sulphides. Scavenging phases could be organic material, Fe or Mn oxides, or fine-grained phyllosilicates. The only scavenging phase that is common to all samples is the phyllosilicate fraction which comprises the bulk of particles finer than 2μ (Fig. 9). This fraction can be isolated easily by centrifugation. Its trace-element content is thought to be proportional to the cation content of sulphides that were present before weathering.
5) Although the -250 mesh (-64μ) fraction may also contain significant amounts of phyllosilicates, these are largely concentrated among particles finer than 2μ. Most of the grains coarser than 2μ are quartz, feldspar, and minor phyllosilicates, a mineral assemblage that is largely chemically inert in terms of its content or ability to take up additional amounts of base-metal cations. Thus, the -250 mesh fraction can be considered to contain two distinct sub-fractions - the "inert" +2μ and the "active" -2μ. Shilts (1971) has pointed out that the ratios of these two fractions vary widely from sample to sample in the Kaminak area, largely because of physical processes peculiar to the active zone (<u>see</u> discussion in Shilts, 1973). Therefore, spurious anomalies are sometimes created by analysis of -250 mesh fractions of clay-rich samples, and "true" anomalies are sometimes masked by low -2μ content of samples near a mineralized zone. Examination of Figures 14 and 18 and comparison of Figures 22 and 23 illustrate this point convincingly. If the -250 mesh maps are used alone, "true" anomalies are present but are difficult to separate from spurious anomalies caused by clay-rich till.
6) Some silicates and other accessory minerals associated with mineralized zones may be enriched in cations common to those zones. Table III clearly indicates this. For this reason, heavy rock fragments and heavy mineral separates that contain no visible traces of sulphides frequently are enriched in cations to the extent that they, too, can reflect mineralization.

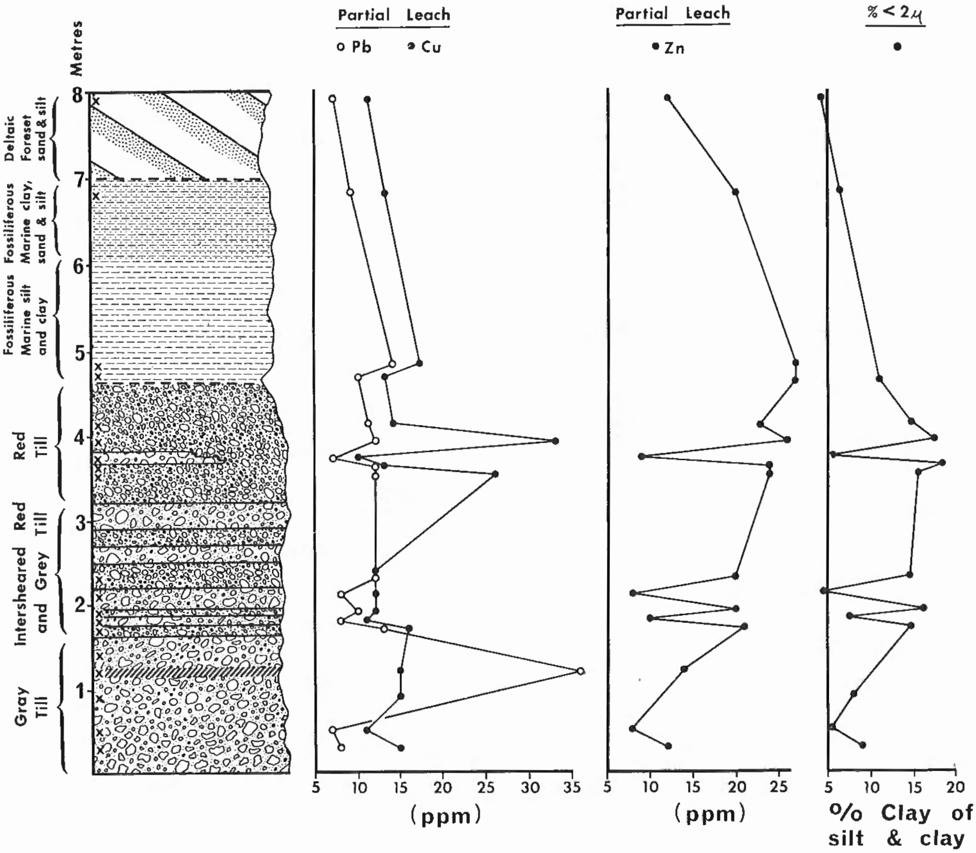
The preceding assumptions are based on comparison of analyses of several fractions of each sample collected. From these comparative data it has been concluded that <u>in the permafrost regime of Keewatin</u>, the -2μ fraction provides the best representation of the original trace-metal composition of highly weathered and physically disturbed till from the active zone. Other fractions can reflect anomalies but do not give results that are as consistent or as readily interpretable as those derived from the clay fraction.

Figure 9 illustrates Cu and Zn values that are typical of various fractions of till from mud boils and from a section of permanently frozen till. The contrast in values for the various "heavy" fractions and clay separates is obvious in this comparison. Scavenging phases (clays) are enriched in Cu and Zn in mud-boil samples whereas "heavy" fractions that contain easily weatherable minerals (sulphides) are generally low in Cu and Zn. The opposite relationship is seen in samples of permanently frozen till.

BEDROCK AND GLACIAL GEOLOGY

Bedrock Geology

Early geological exploration of the area is reviewed by Wright (1967) and Davidson (1970a). Modern mapping done at 8 miles to one inch compiled at 16 miles to one inch resulted in the first comprehensive map of the area and largely defined the limits of the belt, distribution of the major internal plutons, and distribution of post-Archean rocks (Wright, 1967). A program of upgrading to 1 inch to 4 mile scale commenced in 1966. Reports in this series (2° Long. x 1° Lat.) summarizing the Archean geology have been published by Bell (1971), Heywood (1973) and Davidson (1970a, b). The modern work succeeded in dividing the Archean supracrustal rocks



This sequence of glacial and postglacial sediments is typical of most of the Kaminak Lake area, but marine sediments are generally thin or absent. Note variations of trace-elements caused by varying amounts of clay in the <250-mesh fractions of various sediment types.

Figure 14. Stratigraphic section of glacial sediments exposed near northwest arm of Kaminak Lake.

locally into major lithofacies, outlined regional metamorphic gradients, described the Aphebian cover rocks, and defined the contacts of the several major plutonic types. Davidson (1970a, b, c, d) demonstrated with isotopic age determinations and cross-cutting relationships that the majority of felsic plutons intruding the belt are Archean and described the general relations of the Archean supracrustal rocks (Davidson, 1970a, 1972). Very concordant data on zircon concentrates from felsic volcanics indicate a concordia intercept of 2,700 m.y. (R. Wanless, pers. comm., 1973). The history of mineral exploration has been reviewed by Laporte (1972) and Thorpe (1972). Hornbrook and Jonasson (1971) presented data on the distribution of mercury, particularly in lake water.

Stratigraphy of the Kaminak Group

The Kaminak Group is divided into one incomplete and four complete mafic volcanic to felsic volcanic/sedimentary cycles (Fig. 3). The oldest of these (units 1 and 2, Fig. 3) envelopes the Heninga Batholith in the western part of the area. The second and third cycles (units 3 and 4, 5 and 6) envelope all but the eastern extreme of the Kaminak Batholith. The youngest cycle (units 7 and 8) and the incomplete cycle (unit 9) fill a regional synclinorium east of the Kaminak Batholith. No basement has been positively identified.

Centres of felsic volcanism have been defined at points A (Maguse); B (Spi Lake); and C (Quartzite Lake) (Fig. 3). Other centres may be present at D (Turquetil Lake), E (Helika Lake) and F (east of Copperneedle Lake) (Fig. 3). Detailed mapping will probably isolate still others. Centres of mafic volcanism appear to exist at M (Koktok) and N (Southern Lake) (Fig. 3), and there are probably many others.

An unconformity of varying discordance exists at the base of unit 8 in the western half of the area.

Fine- to coarse-grained clastic sediments are a prominent lateral facies of felsic volcanic units 4 and 8. Conglomerates are found adjacent to volcanic centres B in unit 4, E and F in unit 8, and in unit 8 where it unconformably overlies the volcanic centre C in unit 6. Fine-grained clastic sediments are the bulk of unit 8, being particularly abundant in the Wilson Bay area (Fig. 3).

The intermediate to mafic units comprise mainly pillowed and massive flows cut by sills and dykes of similar composition. Primary mesoscopic textures are, in general, well preserved. Flow thicknesses in excess of 400 feet are present locally but probably average 50-100 feet. Interflow materials comprise scoria, tuffs, fine-grained clastic sediments, black shales and many varieties of exhalite. The maximum homoclinal thickness of any mafic unit appears to be 30,000 feet (units 3 and 7). Units 3, 5, 7 and 9 include andesite flows in addition to or in place of the normal tholeiite. Andesite tends to occur at the top of these units.

The felsic units comprise massive and fragmental flows, breccias and tuffs, all intruded locally by thick, sill-like masses of porphyry. Textural and compositional heterogeneity is the rule, including lateral facies variation to sediments. Very coarse, angular breccias ("Mill Rock", Sangster, 1972) were observed in felsic centres A and B. Exhalite is characteristically present either in situ or as "fragments". The maximum observed thickness of any felsic unit appears to be approximately 18,000 feet (unit 4). The felsic units are characterized by rapid changes in thickness and may be absent locally. Compositions are calc-alkaline, ranging from andesite to rhyolite (Table I). Felsic units may show a progression from intermediate compositions at the base to more siliceous varieties at the top.

Structure

The principal structures of the belt are major, east-west trending, doubly plunging isoclinal folds (Fig. 3). A pervasive "bedding plane" foliation or "schistosity" is associated with these folds but its intensity varies markedly and locally the foliation is absent. This folding appears to predate unit 8 in the western part of the area, and is recumbent locally.

Subsequently, the belt was passively intruded by large plutonic masses of tonalitic composition followed by smaller discordant plutons of diverse size and composition. Interference fold structures, apparently related to the intrusions, developed locally in the supracrustal rocks. In synclinal nodes, where the younger axes intersect the older at about right angles, typical interference patterns have been developed, the early surfaces (S_0, S_1) have been folded, primary structures have been transposed, and the pervasive early "schistosity" has been cut by the later "axial plane" (fracture) cleavage (Fig. 3, note structure at Quartzite Lake, and Spi Lake). Although two separate periods of folding-deformation are indicated, the timing of the intrusive activity was not necessarily bi-modal. Thus, "second" periods of deformation may have happened at different times in different areas.

Subsequent strain release was accommodated by faulting, often along anisotropies created during preceding periods of deformation. Observed displacements are small, usually less than 2 miles. The tectonic "grain" of the Hudsonian orogeny has left little imprint on the study area other than as a guide for emplacement of very late Archean alkaline intrusions and structural control of lower Aphebian fault troughs (Ridler, 1973).

Metamorphism

The regional metamorphism has been described by Davidson (1970 a, b, 1972). A central zone of albite/epidote greenschist metamorphism corresponding approximately to the study area is flanked to the north and south by rapidly rising metamorphic gradients of apparent Hudsonian age. However, local zones of higher grade metamorphism envelope many of the larger stocks and batholiths. In short, a central relict zone of typical Superior Province metamorphism of probable Kenoran age is superseded to the north and south by Hudsonian metamorphism. Consequently, in the study area, primary textures at outcrop scale are very well preserved, but primary microscopic textures are not.

Volcanic Geochemistry

Compositions of volcanic rocks are traditionally plotted on standard variation diagrams. In this study so many analyses are available that contouring of population densities of points plotted on variation diagrams becomes possible (Fig. 6, see also Ridler, 1969). On Figure 6, all rocks in which the total of H_2O plus CO_2 exceeded seven per cent were adjusted according to the formula given on the diagram, and the field boundary separating alkaline from

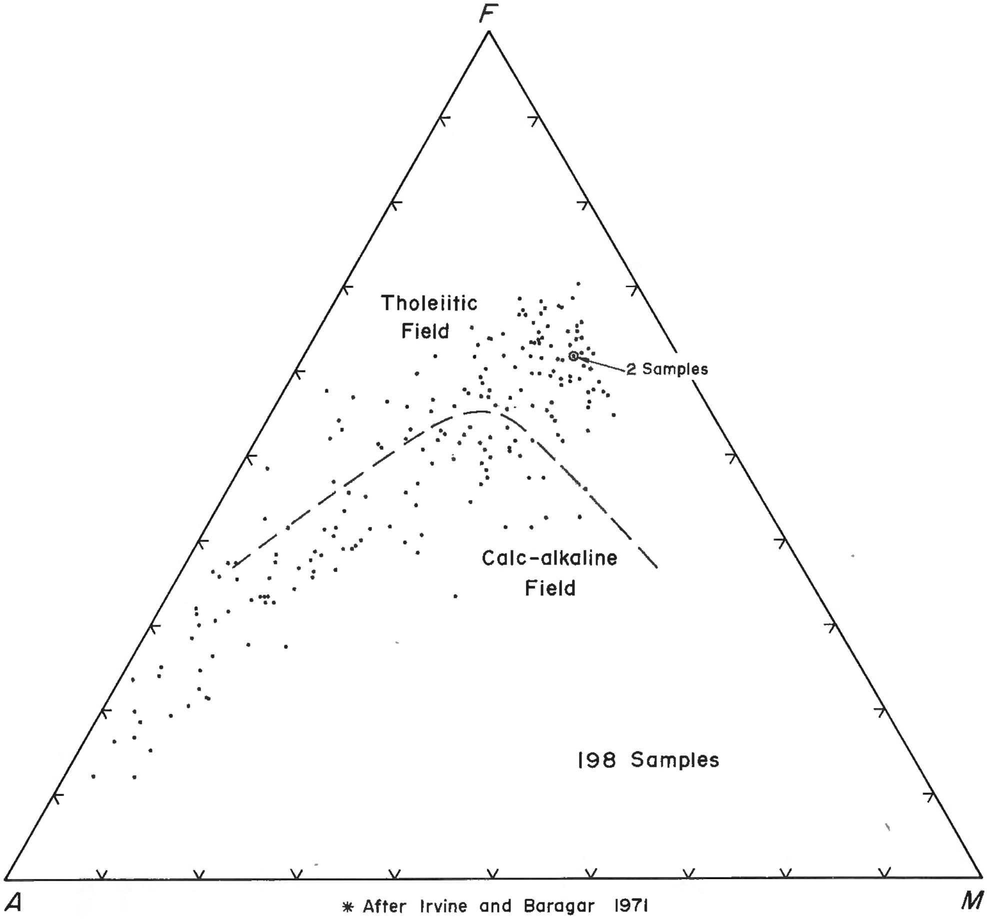


Figure 15. AFM diagram for volcanic rocks, Kaminak Group.

sub-alkaline assemblages (Irvine and Baragar, 1971) is shown. The Kaminak Group is clearly sub-alkaline by this test. Examination of Figure 15 illustrates that the suite is tholeiitic to calc-alkaline, or normal for Archean volcanics.

Because of the sampling method employed it is important to note that the heights of the various peaks or modes on Figure 6 are not a direct function of volumetric abundance of the rock type in the field. However, the occurrence and position of a grouping indicates the presence of a rock-type possessing a chemical composition significantly different from the other groupings present, many of which, in the absence of contouring, are not readily apparent. Several groupings are indicated by their common rock names e.g. basalt, andesite, dacite, rhyodacite, rhyolite. The geochemistry of the Kaminak Group is similar to that of volcanic rocks in the Noranda area, Quebec (Goodwin, manuscript report).

Metallogeny

The two great classes of Archean mineral deposits are those associated with and a function of intrusive igneous processes and those associated with and a function of exhalative volcanic activity.

Included in the former are "porphyry-coppers" and their analogue, "porphyry-golds". The occurrence of porphyry copper mineralization in the Superior Province has been discussed by Kirkham (1972). Disseminated copper mineralization in apparently late felsic porphyritic stocks also occurs in the Rankin-Inlet-Ennadai Belt, but was not the subject of metallogenic investigation. "Porphyry-golds" should be present but none have been found up to the present time by prospecting. The lack of known targets coupled with the difficulty of visual recognition prohibited this latter metallogenic target from investigation in the recent study.

The regional distribution of exhalite facies is indicated on Figure 3. With some exceptions, exhalite within the central zone is predominantly carbonate or sulphide facies, or mixtures of the two. The most extensive zones are distal and possess characteristic compositional layering (chert/ carbonate/ sulphide/ oxide/ silicate). A transported variety comprising pyroclastic rocks with a significant amount of exhalite fragments is also present. Both carbonate and sulphide facies of the fragmental variety have been observed. Chalcopyrite is ubiquitous in small amounts in both the in situ and transported types. Distal exhalites with visible sulphides often carry significant gold (Table II; and Ridler, 1973, p. 172-173).

Proximal sulphide and carbonate exhalite are present in the Spi Lake area (Ridler, 1973). The sulphide facies is polymetallic and carries significant precious metals (Table II). Compositional layering is present but rare. The proximal species examined to date are associated with coarse, fragmental rhyolitic volcanics ("Mill Rock" of Sangster, 1972).

Regional exhalite zones are associated with or are lateral extensions of major volcanic units or of their stratigraphically equivalent clastic sedimentary facies (Fig. 7). Rarely they are superimposed on penecontemporaneous, adjacent, intermediate to mafic lava sequences. Major exhalite zones may occur at any stratigraphic level in the felsic formations, but are commonly a significant distance above the base.

The regional facies zones are much more extensive than the individual volcanic centres (Fig. 3). They may be a function of original basin bathymetry.

Glacial Geology

The Kaminak Lake area was glaciated during the Wisconsinan by continential glaciers that left deposits and landforms with characteristics similar to those found in temperate areas to the south. Because the glacial geology of the region has not been studied intensively, little is known of glacial or interglacial events that might have preceded the late-glacial events that can be inferred from surface features. Striations and till stratigraphy indicate that, at one time, ice may have flowed in a southerly direction from centres of outflow possibly located 100 or more miles north of the region (Lee,1959, Shilts, 1971, 1973). The most prominent glacial episode, for which evidence is abundant, is the late-glacial flow associated with the Keewatin Ice Divide (Lee, et al., 1957; Lee, 1959).

The Keewatin Ice Divide is an elongate centre toward which the western portion of the waning Wisconsinan ice sheet shrank as the climate warmed. While this centre operated, ice flow was radially outward from it. The Kaminak Lake area is east of the centre, and flow was eastward to southeastward throughout the region. Although ice may have flowed in other directions across the study area, surface till and morphological features are associated overwhelmingly with southeastward flow direction. Evidence of the importance of the southeastward flow phase is abundant (Fig. 4):

1) rock outcrops are commonly striated and eroded into southeast-striking roches moutonnées;
2) extensive fluted till plains and drumlin fields have a strong east to southeast grain;
3) surface till is red because of inclusion of abundant specular hematite derived from rocks of the Dubawnt Group which outcrops west and northwest of the area;
4) a fan of garnets (Fig. 4) at least 16 miles long trails southeast from an altered alkaline intrusion that occurs south of Quartzite Lake (Davidson, 1970c);
5) end moraines trend northeast-southwest indicating the general trend of the local ice front; and
6) marine, ice-contact deltas were built from the ice front eastward into the Tyrrell Sea (at the mouths of eastward-flowing esker streams).

As the glacier receded toward the Keewatin Ice Divide, its front stood in the Tyrrell Sea (Lee, 1959). This ephemeral extension of Hudson Bay inundated land isostatically depressed by the weight of the ice sheet, and at one time covered nearly all of the study area. Beaches related to the marine submergence are presently found up to altitudes of 560 feet a.s.l. Marine shells from the base of marine sediments exposed on Kaminak Lake indicate that the Tyrrell Sea was in existence at least 6,600 ± 230 (GSC-1434) C_{14} years B.P. and that the sea still filled the Kaminak-Quartzite-Carr Lake basins 4,590 ± 220 (GSC-1484) C_{14} years B.P. (Shilts, 1973).

Figure 14 represents typical glacial stratigraphy that may be expected in the Kaminak-Carr Lake area. The lower, grey till may have been deposited during the southward flow phase described above. Locally, ice-contact stratified drift replaces the till or separates till from marine sediment. Marine sediment is thin and patchy. The main effect of submergence was reworking of the upper part of till and stratified drift surfaces.

Because the study area is underlain by deep, continuous permafrost, solifluction processes have moved significant quantities of unconsolidated sediments to the bases of most slopes. Thus, the thin zone of marine sediment and reworked drift has disappeared from all but scattered flat areas, and glacial sediments (largely till), for the most part unaffected by submergence, are exposed nearly everywhere that samples were required. For further discussion of the seasonally thawed zone and effects of permafrost on near-surface sampling, the reader is referred to James (1971) and Shilts (1973).

DISCUSSION

Kaminak Group in the Spi Lake Area

Structure

The western portion of the Kaminak Batholith occupies a large structural dome, elongate in an east-west direction (Fig. 7). Units 3 and 4, the Spi Lake Group (proposed name), face away from the batholith but are cut locally by phases of the batholith. Highly discordant plutons near the margins of the batholith have interrupted the continuity of the stratigraphy (Fig. 3) and compressed the supracrustal rocks between.

At the southwestern end of the batholith is a synclinal node formed by the intersection of three synclinal structures (Fig. 3). In effect, the east-west trending regional syncline south of the Kaminak Batholith splits about the Heninga Batholith, one branch continuing to the southwest, marginal to the Turquetil Batholith while the other continues in a northwesterly direction between the Heninga and Kaminak Batholiths. The northern limb of the regional syncline is intersected by a series of later southwest/northeast-trending folds.

Late faulting locally offsets bedding by as much as several thousand feet. Orientation, and probably the timing, of this faulting is diverse. The northern contact of the Turquetil Batholith is associated with a pronounced mylonitic girdle in the overlying supracrustal rocks. The rocks have recrystallized to nodular "paper schists" and competent members (e. g. chert/magnetite exhalite) are prominently boudinaged.

The general structural pattern is simply a series of interfering domes cored by moderately discordant batholiths with intervening, doubly plunging synclines, similar to the structural pattern of the Superior Province in northwestern Ontario (Clifford, 1972). In detail, interference fold patterns may be quite complex, and faulting is significant. Many small-scale features of polyphase deformation are present, such as intersecting foliations of different age, outcrop-sized refolded folds, transposed primary structures, folded and boudinaged quartz veins, and folded or crenulated foliations. This deformation style has affected in varying degree the main exhalite zone in unit 4.

The foregoing discussion relates solely to Archean structural events or what would loosely be called "the Kenoran Orogeny" in the Superior Province. However, the Spi Lake area has been significantly affected by late Archean and "Hudsonian" tectonic events. The most obvious of these is a northeasterly trending series of mylonitic fault zones roughly coincident with the Padlei-Quartzite Lake belt of lower Aphebian Hurwitz Group rocks (Fig. 3). These form an axis along which uppermost Archean alkaline stocks were emplaced (Ridler, 1973). To the northwest, the structural "grain" of the Churchill Province progressively transposes and obliterates the older "Superior Province" structures.

Stratigraphy

The stratigraphy of the Spi Lake area is presented in Figure 16. Each of the four cross-sections is located on Figure 7. At the time of writing only the Kaminak Lake Section has been analytically documented (Fig. 16 and Table I).

The Kaminak Lake section (Fig. 7) comprises a series of intermediate to mafic flow units and intermediate to felsic pyroclastic units, accompanied by exhalite. The basal flow sequence is intruded by the gneissic, granitoid Kaminak Batholith to the south and by highly discordant intermediate to mafic plutons to the east and west. Massive lavas, porphyritic flow breccias and medium-grained sills predominate in the basal portion while pillow lava and interflow tuffs and cherty exhalite become more common near the top. The lavas strike east-west to east-southeast and, based on numerous top determinations from pillows, face north. The typical composition is andesitic or tholeiitic basalt (Table I) but dacitic interflow tuffs occur near the top (Fig. 7). The correlative formation in the Maguse Section appears to be much more tholeiitic. The unit is approximately 19,000 feet thick. Individual flow thicknesses have not been determined for this particular mafic sequence.

A series of dacitic to rhyolitic tuffs, fine breccias, flows, and exhalite overlies the basal flow unit. These units appear to be distal facies correlative with the main felsic unit at Spi Lake (Figs. 7 and 16). The main exhalite zone is well-banded, mixed facies but is predominantly pyritic chert/siderite, and is highly diluted locally with pyroclastic material. The exhalite may be as much as 200 feet thick but is highly folded. No underlying alteration zones were observed. The overall thickness of the felsic unit is approximately 1,500-2,500 feet. To the west, the main exhalite zone is overlain by more felsic volcanics a few hundred feet thick; to the east, it interfingers with and is overlain by highly carbonated basaltic pillow lava (Table I).

The succeeding cycle (units 5 and 6, Fig. 7) is a complex assemblage of massive and pillowed basaltic and andesitic flows interfingering with and overlain by felsic pyroclastic tuffs, hypabyssal intrusives and in situ and reworked carbonate facies exhalite. The lower, predominantly intermediate to mafic sequence is approximately 12,000 feet thick, and the upper, predominantly felsic sequence (including one andesitic flow sequence approximately 3,000-4,000 feet thick) is about 20,000 feet in maximum thickness. This unit is correlative with the large domical mass of felsic volcanics and intrusives between northeast Kaminak Lake and Quartzite Lake (Fig. 7). It is overlain by "amoeboid" flow breccias, and massive and pillowed andesites and basalts of unit 7 occupying the core of the regional syncline north of the Kaminak Batholith (Fig. 7).

This sequence of andesitic flow units and rhyolitic pyroclastic units bears a remarkable resemblance to the stratigraphic sequence of the Noranda camp in Quebec.

In detail the structure of the Spi Lake area is very complex (Fig. 7). A major, older, east-west trending syncline is crossed by a younger, regional anticlinorium. In effect, the synclinal axis appears to bifurcate as described previously. The resulting pattern leaves most of the major part of unit 3, the basal mafic phase of the Spi Lake Group, and the major part of unit 4, the felsic upper phase of the Spi Lake Group, striking northwest-southeast and facing each other. At Spi Lake the base of the felsic unit has been intruded by the western extremity of the Kaminak Batholith. However, seven miles to the east, the felsic unit is less than 1,500 feet thick while the underlying mafic unit (unit 3) is approximately 12,000 feet thick. Similarly, immediately to the southwest, the northeast-facing mafic unit of the group is approximately 30,000 feet thick on the crest of the anticline.

The oldest volcanic cycle (units 1 and 2, Fig. 3) is found only on the limbs of the dome about the Heninga Batholith. Within the map-area (Fig. 7) it has the shape of a large open anticline, concave to the southwest. It comprises a basaltic lower sequence, a maximum of 15,000 feet thick, overlain by a dacitic complex, a maximum of 15,000 feet thick, including two major zones of exhalite (Ridler, 1973).

The greatest thickness (about 18,000 feet) of the Spi Lake felsic unit is in the vicinity of Spi Lake, an increase from 1,500 feet seven miles to the east. Very coarse breccias (fragments up to 2 feet in diameter) are present locally. Rhyolite is abundant, including some uniform flows or high level intrusions. Mafic units on all sides thin as they approach the centre. A thick polymict conglomerate/arkose unit flanks the felsic unit to the north. The main exhalite zone varies greatly in width (from a matter of inches to many tens of feet over strike lengths of a few hundred feet), and degree of dilution and, at least at two localities (nos. 17 and 18, Fig. 7), possesses a well-developed magnesian alteration pipe. At Spi Lake the pipe displays dalmatianite texture (Julian Boldy, pers. comm.). Cherty, layered tuffs are present. These features are all consistent with the interpretation that the accumulation represents a felsic volcanic centre.

The high degree of deformation plus the increase in metamorphic grade in the supracrustal rocks northwest of Spi Lake may have a pronounced effect on the continuity, shape, mineralogy and grain size of any contained exhalite zone. Commonly, originally lensoid stratiform bodies become cigar-shaped, dismembered and/or transposed into a later foliation in this type of structural/metamorphic setting (Coats, et al., 1970).

Metallogeny of the Main Exhalite Zone

Major Archean felsic volcanic formations are characteristically accompanied by economic mineralization (Goodwin, 1965). Mineralization may occur either as disseminated mineralization in various degrees of remobilization into "epigenetic" veins (usually with quartz and/or carbonate) or as relatively undisturbed exhalite.

Exhalite may be mined for its major sub-facies (e.g. iron as oxide, or carbonate (rarely sulphide)) or more commonly for its quantitatively minor sub-facies, e.g. copper and zinc (always sulphide facies), gold and/or silver (commonly sulphide or sulphidic carbonate facies). In this regard the distribution of facies is critical. For the Spi Lake Group, the zone separating the oxide from the carbonate/sulphide facies appears to trend about east-west and to be located just north of Turquetil Lake (Fig. 3). Another facies boundary separating carbonate from sulphide facies may be present just south of Spi Lake. The facies boundary separating the carbonate/sulphide zone from the oxide zone to the north lies north of Quartzite Lake (Fig. 3). The northern carbonate to sulphide boundary has not been defined. By this analysis, the greatest proportion of the Spi Lake Felsic centre lies within the sulphide facies.

The trace of the main zone of exhalite is indicated diagrammatically on Figure 7. The position of the folds shown two and one half miles northwest of Spi Lake is largely conjectural, being based partially on drift geochemical information. All locations where the main zone has been positively identified are indicated (Fig. 7). It appears that the main zone can be traced around the entire Kaminak dome, with only local interruptions, whereever there are supracrustal rocks. Locations 18, 28, and 25 (Fig. 7) were found by extrapolating the known stratigraphy through known structure. Location 18 has no magnetic expression while that at locations 28 and 25 is minimal or problematical (Fig. 8).

Larder Lake-type carbonate exhalite (Ridler, 1973), up to 75 feet thick, has been found or identified within the Spi Lake felsic unit at three localities. One long zone has apparently been repeated by the syncline northwest of the western margin of the Turquetil Batholith. (Fig. 7). On the northwestern limb of this structure the exhalite zone rests upon the uppermost basalts of unit three and is associated with laminated argillites. This zone is overlain by rocks of felsic unit 4. Another zone, east of Turquetil Lake (Fig. 7) and possessing a thin zone of laminated chert, lies at the apparent top of the Spi Lake felsic unit and is overlain by the basal flows of unit 5. The remaining occurrence, north of Turquetil Lake, appears to lie near the top of the felsic unit over a magnesian alteration zone in association with argillaceous sediments and minor cherts and, at loc. 16 (Fig. 7), appears to be folded into a north-opening anticline. This apparent variation in stratigraphic position is in marked contrast to the main exhalite zone, discussed previously, which everywhere observed lies at some significant distance above the base of the felsic unit (Fig. 7). Also, unlike the main exhalite zone, the Larder Lake-type exhalite crosses facies boundaries without noticeable change in composition. Without additional evidence, it appears that more than one stratigraphic horizon of Larder Lake-type carbonate may be present.

Gold in Exhalites of the Kaminak Group

It is a truism of mineral deposit geology that a worldwide association of gold mineralization and "iron-formation" exists. Accepting that "iron-formation" is just a special type of exhalite, and that the other facies of exhalite (sulphide, carbonate, silicate, etc.) are also a universal habitat for gold mineralization, the truism more properly stated is that, "many gold deposits are associated with exhalite".

In the last several years exploration for base-metal-rich massive sulphide deposits has been directed towards "old gold camps". This is a reflection of the fact that base-metal-rich massive sulphides are no more than a special kind of exhalite. Areas that have gold deposits (often in varieties of exhalite) have a greater probability of also having base-metal deposits. Goodwin (1965) demonstrated this relationship for the Abitibi Belt and further that the several juxtaposed varieties of mineral deposits appeared to coincide with thick accumulations of intermediate to felsic volcanic rocks. However, about 500 neutron-activation gold analyses of the volcanic rocks by Goodwin (pers. comm.) demonstrated that with a few exceptions all were at or within an order of magnitude of background (0-10 ppb). Ridler (1970), analyzing varieties of exhalite from the main exhalite zone at the south margin of the Abitibi Belt, one of the world's greatest gold producing areas, found a range in excess of four orders of magnitude. Also, the high values are consistently related to sulphide varieties of exhalite, although sulphidic varieties are not necessarily anomalously rich. Field relations suggested that the gold mineralization was primarily syngenetic with varying degrees of redistribution in late metamorphic gold/quartz veins. These observations are supported by the experimental work of Weissberg (1970). The mineral deposits are related to the exhalative process and may thus be found associated with coeval volcanics or sediments known to be relatively poor in exhalative elements.

The foregoing relationships and results suggest that the economic potential of any Archean "greenstone" belt for precious and base-metals may be ascertained by determining the gold content of the regional exhalite zones, other factors such as volcanic stratigraphy, exhalite facies zonation, etc. being favourable.

All known and discovered varieties of exhalite were subject to metallogenic investigation and later analysis for precious metals. A summary and brief discussion of some of the results is given in Ridler (1973). A range (0-10,000 ppb) similar to that in the exhalites at the south margin of the Abitibi Belt was established, although the proportion of high assays was lower. The lower proportion of high assays is probably a function of the fact that there are as yet no established gold camps or mines in the belt to bias the sampling.

Recently, about 100 more samples were assayed from the Spi Lake area to supplement and extend those already completed. An illustrative selection of results is presented in Table II and located on Figure 17.

The range (0-20,000 ppb Au) for the area is similar to the Abitibi Belt. Sulphide varieties show the greatest enrichment although some sulphide-rich specimens are very low. Varieties of exhalite from Spi Lake felsic unit 4, and interflow units that succeed it have anomalous enrichment. A major, mixed-facies exhalite zone with much sulphide associated with the older felsic unit (unit 2, Fig. 3) also shows slightly anomalous enrichment.

Within the Spi Lake felsic formation, moderately anomalous gold values and markedly anomalous silver values were found in samples from the main exhalite zone at the Spi Lake showing (Fig. 7). In addition, highly anomalous gold values were obtained from the Larder Lake -type carbonate zone at the north end of Turquetil Lake (showing indicated by Davidson, 1970a).

As might be expected, varieties deficient in sulphide, such as magnetite-chert exhalite, and siderite/chert exhalite failed to return any significantly high values.

These data suggest that the economic potential of the exhalites of the major felsic units, and in particular unit 4, is excellent.

Results of Till Sampling and Analyses

Maps showing anomalous concentrations of Cu and Zn are presented for four fractions separated from till collected in the vicinity of Carr Lake and for two fractions separated from till collected near Kaminak Lake. The mineral components of each fraction are distinctly different (see discussion under "Methods") and a brief explanation is required for each map so that results may be better understood.

Clay Fraction (Figs. 18 and 19)

These maps show the distribution of anomalous amounts of Cu and Zn in the -2μ fraction of tills. The -2μ fraction comprises mainly phyllosilicates with minor amounts of quartz and feldspar. Finely divided primary hematite from redbeds of the Dubawnt Group, located about 80 miles northwest of the sample area, also occurs in the -2μ fraction.

The cation content of this fraction is thought to be directly proportional to the amount of cations that were made available by the weathering of primary sulphides, i.e., the greater the amount of copper-bearing sulphides present in unweathered till, the greater the concentration of Cu ions released by weathering and the greater the amount of cations scavenged by the phyllosilicates. This interpretation presumes that the cation exchange capacity (CEC) and clay-mineral composition do not change radically over the area and that the background content of Cu and Zn within the original phyllosilicate structure is relatively constant. It should be noted that these phyllosilicates are the finest products of glacial abrasion ("rock flour") and do not have a significant component derived in situ from hydrolysis of other silicates. They are primarily well-crystallized chlorite and kaolinite with 10Å micas. Weathered samples contain some poorly crystallized non-expansible vermiculite and mixed-layer clays.

To summarize, the amount of cations extracted from this fraction by a strong acid leach should be proportional to the original amount of base-metal-bearing sulphides in unweathered till.

Silt and Clay Fraction (-250 mesh, -63μ) (Figs. 22 and 23)

Although this fraction also contains phyllosilicates, the variation of their proportions (and thus, their CEC) from sample to sample can cause variations in apparent background values that are as great as potential variation between background and anomalous samples. (See "Methods" and Shilts, 1971.) Thus, although most of the anomalies defined by the clay analysis can be seen on the -250 mesh maps, many spurious anomalies are present and meaningful interpretation of these maps is difficult.

Methylene Iodide Separates (SG>3.3) (Figs. 24 and 25)

If unweathered till could be sampled in this area, this fraction would probably provide the most useful results from a drift prospecting point of view. Work by the second author in Quebec and work by Skinner (1972 and pers. comm., 1973) has demonstrated convincingly the advantages of methylene iodide separates from unweathered till over bromoform, -80 mesh or -250 mesh separates. However, sulphides do not persist long when subjected to oxidation, and although typical, unweathered, frozen tills from the study area contain abundant sulphides, sulphides are rare in the acid (pH3.5-7.0), highly oxygenated active zone which exists on the till slopes that were sampled. Thus, analyses of heavies from the active zone are likely to give sporadic patterns, depending on how much sulphide has persisted in the till under local weathering conditions.

In practice, the methylene iodide results, although available for only a portion of the Carr Lake area, give coherent patterns for copper, and patterns derived are similar to those developed from analysis of the scavenging portions of the till. Lead values are also generally high but show little contrast (results for Pb not presented here). Zinc shows almost no contrast and gives only one weak anomaly in the vicinity of the large mass of sphalerite in the Spi Lake showing.

Methylene iodide separates should not be used alone to develop anomalies in this environment, but may provide convincing back-up information when used in conjunction with other, mineralogically dissimilar fractions, such as clay.

Heavy Rock Fragments (SG>2.85) (Figs. 20 and 21)

Within this fraction are small fragments of rocks rich in ferromagnesian minerals or with inclusions of metallic minerals such as magnetite, hematite, or sulphides. In this area the fraction typically comprises fragments of basic to intermediate volcanic rocks and gabbros. Granitic, felsic volcanic, and sedimentary rocks and most of the far-travelled fragments derived from the Dubawnt Group are generally excluded from this fraction. Also, sulphide-bearing felsic volcanics are probably not present because of weathering conditions in the active zone.

The copper and zinc patterns derived from these analyses are largely unlike those from the other fractions discussed. Zinc seems to be concentrated in the northwest one-third of the Carr Lake grid whereas copper is concentrated primarily (but not exclusively) in the southern two-thirds. The break between the two areas of concentration roughly follows a metamorphic isograd sketched by Davidson (1970b). Zinc is prominent in the higher grade zone. No explanation is presented here for these patterns. The cation values are thought to be derived primarily from the ferromagnesian silicates in the rock fragments and may represent no more than the relative abilities of some or all of those minerals to hold Z_n and C_u within their structures under varying metamorphic conditions.

Interpretation of Anomalies in Various Fractions of Till

Copper in Clay

The distribution of copper in the very fine grained fraction of the tills (<2 microns) is irregular (Figs. 13, 18). The anomalously high zones are themselves quite "lumpy". This feature is, in part, due to the wide sample spacing or lack of resolution relative to the size of bedrock features of interest. However, as discussed previously, the distribution of the proximal "pods" on a thin regional exhalite zone is itself "lumpy". It appears, therefore, that the target geometry is at least partly responsible for the distribution pattern. An example is the peak just down-ice from the known occurrence at Spi Lake (Fig. 18).

In general, the anomalously high copper zones faithfully correspond to the main Spi Lake felsic unit (unit 4, Fig. 7)*. In addition, the peaks lie close to the main exhalite zone or its supposed extensions or may be associated with Larder Lake-type carbonate exhalite (Fig. 18). It is possible that undiscovered additional exhalite zones may exist near the focus of felsic volcanic activity at Spi Lake. Since the anomalies are the same size as that associated with the occurrence at Spi Lake they might also be considered exploration targets.

A distinct Cu anomaly also appears to be associated with the felsic unit 6 (Fig. 18). The large mass of felsic volcanics lying between Quartzite and Kaminak lakes and its correlatives to the southwest are particularly

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* Very high lead values were found in this zone on an island 1.3 miles southeast of the Spi Lake showing (Shilts, 1972, p. 188); see results for sample C25I, Table III.

favoured. In situ and transported carbonate and sulphide exhalite zones, some showing marked gold enrichment (locs. 39 and 46, Fig. 17) are present. Both of these sites have coincident Cu anomalies on Figure 15. The presence of coarse breccias and high level felsic porphyries, the great thickness of the unit between the lakes, the relatively high level in the regional stratigraphy and the abundance of rhyolite (for details refer to Ridler, 1971b, 1971c, 1972) suggest a felsic volcanic centre of major economic significance. One of the most pronounced anomalies on Figure 18 occurs down-ice flow from the known occurrence of "Mill Rock" (op. cit.) containing abundant sulphide exhalite fragments (loc. 42, Fig. 17). A highly favourable exploration environment with probable targets is indicated.

A broad "down-ice" Cu anomaly heads on a younger porphyritic felsic intrusive (adamellite of Davidson, 1970b) between Carr Lake and Kaminak Lake. Disseminated copper mineralization giving rise to local malachite staining has been observed in identical rocks south of the long bay of northwest Kaminak Lake. The reader is referred to Kirkham (1972) for a discussion of the economic potential of Archean porphyry coppers. It is entirely plausible that intrusive equivalents of major felsic units containing base-metal-rich exhalites may themselves be rich in base-metals. However, no genetic link has as yet been established in this particular case.

Another source of Cu anomalies appears to be the discordant gabbroic-dioritic border phases of the Kaminak Batholith, especially near the northeast and southeast limits. The mineralization appears to be as late vein fillings or disseminations. The thick accumulations of mafic to intermediate lava which may be the extrusive phases of the above intrusives also commonly bear copper as chalcopyritic disseminations and laminae in flow tops and minor interflow exhalite. The analogous but stratigraphically younger (unit 7, Fig. 3) possesses several Cu anomalies of such derivation, particularly distributed around the periphyry of the large felsic volcanic mass between Quartzite and Kaminak lakes. The economic potential of this metallogenic type appears to be unpredictable.

The large block of samples taken north of Quartzite Lake, including one area sampled in more detail (Fig. 11), contains very few anomalies. The area is also mainly within oxide facies (Fig. 3). The lack of Cu anomalies is consistent with the expectation that the target polymetallic proximal sulphide exhalite would not occur within the oxide facies.

There are a few other anomalies for which the currently available information suggests no bedrock explanation. An example occurs ten miles north of Spi Lake in a granitoid terrain, and several more lie south of Quartzite Lake in similar terrain.

Zinc in Clay

Many of the anomalies discussed previously for copper in clay (Figs. 13, 18) are repeated on Figure 19. In particular, the anomalies related to exhalite in felsic stratigraphic units 4 and 6 stand out. This correspondence is consistent with the habitual occurrence of these metals together in proximal sulphide exhalite.

Copper anomalies related to the possible "porphyry" occurrence and the gabbro/basalt environment are less consistently repeated by zinc anomalies, a reflection of the normal exclusion of significant zinc from these environments. The occurrence of any degree of zinc correspondence suggests that the parent, probably sulphide, material was rich relative to background silicates in both metals but probably not rich in an economic sense for zinc. Alternatively, these anomalies may be entirely spurious.

Copper in Rock Fragments

A reasonable degree of correspondence with the "copper in clay" pattern (Fig. 18) exists in Figure 20. In the case of the felsic volcanics, particularly the main exhalite zone of felsic unit four, it appears that copper-rich, magnesian material from alteration pipes or zones beneath proximal deposits may be responsible for anomalies coincident with those of Figure 18 (e.g. Spi Lake). Alteration pipe sources often have more widely distributed mineralization of lower tenor than their associated proximal pods. Thus, one might expect resulting till anomalies to be less pronounced and more diffuse, and this does appear to be the case on Figure 20.

An anomaly is developed over an extension of unit 4, 15 miles north-northeast of Spi Lake. No corresponding anomaly exists for the clays on Figure 18. Base-metal mineralization does occur in the immediate area but was not examined by the first author. It may be that an alteration pipe or zone exists at this locality but that the co-genetic proximal pod, normally present, never formed or was removed later, leaving a "decapitated" pipe.

A strong correpondence of anomalies exists on Figures 15 and 18 for the possible "porphyry" occurrence. There are insufficient data to properly interpret this feature.

No obvious correspondence exists with basaltic/gabbroic units rich in ferromagnesian source materials. It may be that the heavy rock fragment fraction of this rock type does not bear cupriferous minerals, particularly after weathering. However, these data may not be a fair test of this notion since data are not available for the intermediate to mafic plutonic/volcanic complexes marginal to the eastern Kaminak Batholith.

Zinc in Rock Fragments

Unlike Figures 18 and 20, the pattern of distribution of zinc in rock fragments (Fig. 21) does not appear to correspond with known bedrock features. Values tend to be higher to the northwest. The only corresponding geological phenomenon is an increase in metamorphic grade.

Copper in -250-mesh

Not all the anomalies indicated on Figure 15 are duplicated on Figure 22. Some anomalies have been diminished and restricted, and many spurious anomalies appear that are associated with clay-rich till and not necessarily with mineralization.

Zinc in -250-mesh

Some of the anomalies present on Figure 19 persist in this size range (Fig. 23) but the patterns are very difficult to interpret. As with copper (Fig. 22) many, apparently spurious, anomalies appear, particularly over the Kaminak Batholith. The most prominent anomalies appear on the south side of the north arm of Kaminak Lake where there is known exhalative mineralization, but also where most of the mud-boil samples were of very clayey till.

Similar strong anomalies do not occur in the clay-poor till that occurs near the Spi Lake exhalite zones.

Copper in Heavy Minerals

Some of the anomalies present on Figure 15 are reproduced by this technique (Fig. 24). One of the exceptions is the Spi Lake occurrence which is largely missed.

Zinc in Heavy Minerals

Except for a restricted anomaly associated with the Spi Lake occurrence little zinc remains in the heavy mineral separate (Fig. 25). From these analyses and several hundred other heavy mineral (s. g.>3.3) analyses not presented on Figure 25, it is apparent that zinc is always uniformly low in this fraction, which in unweathered samples should contain zinc-bearing minerals of economic significance. Thus, it can be concluded that zinc values from all other fractions of these samples are derived almost entirely from silicates, either with zinc in their structures or with zinc adsorbed on their crystals.

CONCLUSIONS

Targets of significant economic potential can be defined in Archean "greenstone" belts that have extensive glacial cover and deep permafrost. The methods described in this paper involve a series of steps that focus attention on progressively smaller target zones. The steps are:

1. Establish the presence of calc-alkaline volcanics.
2. Establish the precious metal range and the regional distribution of exhalite facies.
3. Establish the presence of felsic volcanic centres and their main exhalite zones within the sulphide facies zone by regional stratigraphic analysis.
4. Sample the tills over the established felsic volcanic centres and analyze the clay fraction ($<2\mu$). Ideally, methylene iodide or other heavy mineral separates of the coarser grains should be analyzed also to confirm clay anomalies.

The study of the Rankin Inlet-Ennadai Belt and Spi Lake areas led to the indications of target zones of economic potential in a region without past or present producing mines. Specific targets of high economic potential are indicated in a geological environment very similar to the south margin of the Abitibi Belt.

The ultimate proof of any exploration method or combination of methods is whether it (they) can lead directly or indirectly to discovery of economic mineralization. As the scope of operation of the Geological Survey permits only limited follow-up to data such as those presented in this paper, our approaches can only suggest possible lines of research that might be pursued to find economic mineralization in such "greenstone" belts. It is our opinion that this integrated approach can lead and has led to discovery of interesting target areas, because both techniques, although conceptually very different, have outlined similar areas of interest. The fact that there was little exchange of ideas or information until the final maps were completed makes the correspondence of the data particularly exciting to us. It is our hope that this excitement is justified and that such an integrated approach may be found to be equally applicable in other glaciated, mineralized belts.

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