EDITOR-IN-CHIEF:
Chris Mamen
MANAGING EDITOR:
Allan T. Muir
ASSISTANT EDITOR:
Richard A. Garlick
GRAPHICS CONSULTANT:
Paul Abell
EDITORIAL SECRETARY:
J. Olive
CORRESPONDENTS:
Australia: K. Smith
Britain: Dr. G. Abrahamson
Canada: A. E. Cave
South Africa: G. M. Thain
United States: J. M. Bird
ADVERTISING SERVICES:
M. St. Jacques
MANAGER:
Terry Tucker
PUBLISHER:
K. McCOLLUM
GROUP PUBLISHER:
J. V. Deragon

Canadian Mining Journal is published monthly by National Business Publications Limited (a wholly-owned subsidiary of Southam Business Publications Limited) with editorial and executive offices at Gardenvale, P.Q. M. G. Christie, Chairman of the Board; A. W. Dancey, President. **Telephone** (514) 453-3330; **telegrams and express** (CNR and CPR) Ste. Anne de Bellevue, P.Q. Second class mail registration number 1340. Return forms 29B and 67B to Gardenvale, P.Q. Legal deposit Quebec National Library.

Subscriptions — Canada: one year $8, two years $12. British Commonwealth and United States: one year $15, two years $25. All other countries: one year $20, two years $30. Single copies — Canada $1; other countries $2.

Change of address — please notify Circulation Department at least four weeks in advance, giving new address and enclosing old address label from magazine cover.

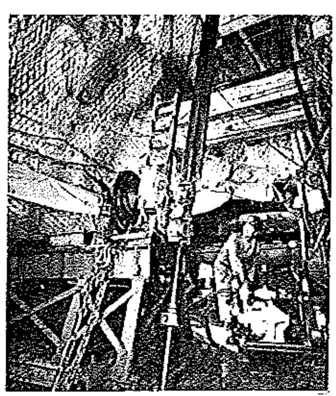
SALES OFFICES:

Montreal 128, Que., Commerce House, 1080 Beaver Hall Hill, Suite 1712, Tel. (514) 878-2671 (G.E. Holgate, Advertising Representative). **Toronto 289, Ont.**, 6 Crescent Road, Tel. (416) 923-7313 (W. H. Hewitt, Advertising Manager). **Vancouver, B.C.**, Curtis Media Representatives Limited, 17-636 Clyde Avenue, West Vancouver, Tel. (604) 922-2314. **New York**, G. E. Holgate, 1080 Beaver Hall Hill, Suite 1712, Montreal 128, Tel. (514) 878-2671. **Chicago, Ill.**, W. H. Hewitt, 6 Crescent Road, Toronto 289, Ont. Tel. (416) 923-7313. **United Kingdom**, Norman F. Keenan & Associates, Walmer House, 296 Regent Street, London, W. 1, England, Cable address: NEENAK. — **Closing date:** Copy and cuts should be in publisher's hand not later than the 17th of the month preceding publication if proofs required. Closing date for all copy and cuts is 24th of month previous. Rates and all information will be supplied upon application to Gardenvale or to any Sales Office listed on this page.

NATIONAL BUSINESS a National Business publication

Canadian MINING JOURNAL VOL. 92, NO. 4 APRIL 1971

INCORPORATING MINING IN CANADA



COVER STORY

Despite recent improvements and advances in geophysics and geochemistry, diamond drilling is still the ultimate tool in assessing potential mineral deposits. The cover picture for this year's Prospectors issue is a departure from the conventional tripod surface installation and shows instead a typical clean, brilliantly lit electric diamond drilling station underground at an Inco mine. The wire line system used here has been a real breakthrough in eliminating drudgery and increasing output. The driller is operating the wireline hoist to retract the overshot and core tube assembly, obviating the necessity of pulling up the entire string of rods to recover core. Photo courtesy Inco Triangle.

CMJ EDITOR'S PAGE

The Prospectors and Developers special issue

"The seventies — the prospectors' challenge" proved an apt theme for the 39th annual convention of the Prospectors and Developers Association at the Royal York Hotel in Toronto, March 7 to 10. Each of the large number of delegates acclaimed the 1971 meeting as being successful on every count and none could deny they were unaffected by the spirit of unbounded enthusiasm and optimism which permeated all proceedings as well as informal talks and discussions. While the challenge admittedly will definitely be there during the seventies and thereafter, to find the minerals which will be in ever-growing demand, the meeting also strove to provide some of the answers as to how and where to look, pointing out also problems and possible solutions. The exceptionally heavy technical program contained a great deal of useful information on a variety of related topics of interest and value to those engaged in mineral exploration.

CANADIAN MINING JOURNAL again devotes its April issue to the cause of the ore seekers in Canada through publication of papers or abstracts of papers presented at the recent Prospectors and Developers Convention. Editorial space limitations this year have seriously affected the number of papers it has been possible to publish in full for which apologies are extended those authors who had taken pains to prepare written presentations and illustrations. Included in full are those offering guidelines to prospecting and mineral exploration, while papers dealing with where to look in the various provinces and elsewhere have been abstracted and condensed. In an effort to provide interested readers with copies of the full papers CMJ is prepared on request to offer Xerox prints of available original manuscripts at cost.

24th International Geological Congress and Georama 72

The International Geological Congress, held every four years, will be held in Canada in 1972 with Montreal being the host city. The previous congress took place in Prague in 1968.

Over 160 sessions and symposia are scheduled and 100 field trips across Canada are on the program. Many related international associations and societies and commissions are involved in the Congress which will attract the largest number of Geoscientists from all over the world ever to assemble in Canada.

All exhibitors will be sent a manual of instructions which will explain every aspect of their participation in Georama 72. This will include move-in details, shipping and customs clearance, and other pertinent information.

To ensure the success of Georama 72, the 24th International Geological Congress has engaged the professional show management service of Southex. Southex is Canada's leading producer of trade shows so exhibitors are assured that every detail will be looked after with courtesy and despatch.

Georama 72 is the first time an exhibit section has been attached to the International Geological Congress. It is a new display concept of national geological maps and related materials traditionally shown at past congresses.

For the first time, national exhibits and carefully selected commercial exhibits will combine in one of the world's most modern and deluxe exhibition salons, Place Bonaventure, in the heart of metropolitan Montreal.

Readers are advised to make an early decision to ensure their participation in Congress proceedings. field trips, and the exhibit section. Write: 24th International Geological Congress, 310 Victoria Avenue, Suite 201, Montreal 215, Quebec, Canada.

GUIDELINES TO PROSPECTING and mineral exploration

Molybdenum, tungsten and uranium in acid plutonic rocks as a guide to regional exploration, S. E. Yukon

By ROBERT G. GARRETT*

In order to appraise the usefulness of broad regional geochemical rock sampling surveys as an aid to mineral exploration a program has been initiated in the Cretaceous acid plutonic rocks of the Selwyn belt in the Yukon and Northwest Territories. The study area lies northeast of the Tintina Trench between the latitudes of 60°20′N and 64°40′N. K-Ar dates for the intrusives range from 74 to 110 million years and the plutons are intruded into sedimentary and regionally metamorphosed rocks of Proterozoic to Mississippian age.

There is currently some dispute over the age of the Yukon Group schists of the Keno Hill-Dawson area, ages as young as Cretaceous have been proposed and Mesozoic fossils have been found near Dawson. Others prefer a Proterozoic age and much work will have to be undertaken in this structurally complex area before the problem is resolved. The Selwyn belt was chosen for a variety of reasons, three of the most important being: 4 mile mapping was complete or underway, the area contains several known mineral deposits and a multitude of showings which are genetically linked to the intrusives, and for the most part there is good to excellent exposure.

To date only a few broad regional geochemical rock sampling programs have been carried out in the western world. The greatest effort in the evaluation of primary geochemistry has been made in the U.S.S.R. and numerous papers appear in the Russian journals on the subject. The object of these surveys, both the Russian and our own, is to make a mineral potential appraisal of a large area of country. The aim of the broad regional survey is not to delineate staking targets but rather to define areas in which it would be most advantageous to concentrate effort in the search for certain types of deposit. Obviously, a program such as that currently underway which is restricted to acid plutonic rocks will only be of use in exploration for deposits which have a direct genetic relationship with the intrusives.

The tungsten deposits of current economic importance, i.e., the Canada Tungsten mine and the AMAX property at Mount Allan, are skarns developed in Lower Cambrian limestones at or near contacts with the intrusives. The alluvial gold of the Mayo area is associated with scheelite and cassiterite and the source of the gold and these minerals is veins and veinlets in and around intrusives which are close to the alluvial workings. Some would argue a similar classical hydrothermal origin for the Keno Hill lead-zinc-silver deposits, while others propose the intrusions only provided heat to stimulate a plumbing system and that the metals were derived from the surrounding host rocks. It is unlikely that a direct link exists between the intrusives and the strata bound lead-zinc deposits at Faro, Vangorda and Swim Lakes near Ross River or the Tom deposit at McMillan Pass.

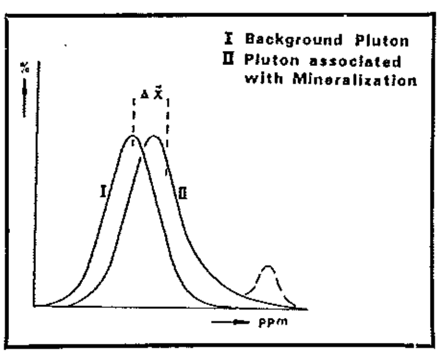


Fig. 1 Idealized distribution of trace elements in acid plutonic rocks

The distribution of trace elements in acid plutonic rocks has been a point of discussion for many years, and the argument of normal versus log-normal distribution will undoubtedly continue. It is proposed that less positively skewed, more normal, distributions are typical of plutons devoid of any concentrations of elements into mineral deposits. In contrast a more skewed distribution, perhaps lognormal, or a bimodal distribution is more typical of plutons associated with mineral deposits. The means of these distributions may be very similar (Fig. 1) making the search for plutons associated with mineral deposits difficult if only the means are considered.

The implication of these frequency distributions is that sufficient samples

*Geological Survey of Canada, Ottawa

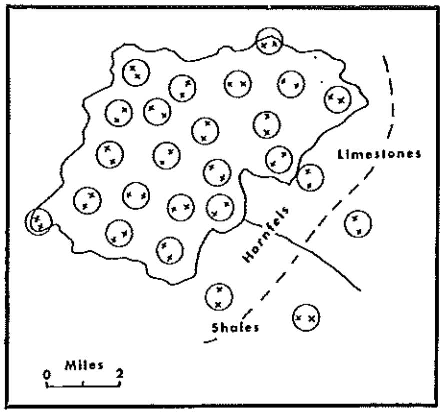


Fig. 2 Practical pluton sampling scheme

must be collected to ensure that some will be drawn from the skewed part of the distribution if it exists. If the critical number of samples can be determined, one can then state that if any samples from the pluton exceed some critical value it is likely to be associated with mineralization. Thus, it can be seen that the range of the data and the shape of the distribution are equally as important as the mean. In the current work the arithmetic means have been computed as these improve the contrast between background and anomalous plutons. It would be more correct to compute geometric means, but as these reveal exactly the same patterns as the arithmetic means, only at a lower contrast, the arithmetic means have been used in this presentation.

TABLE I Geographic location of features referred to in the text

Location	Map sheet	UTM coordinates	Lat.	Long.
Potato Hills	106D	8 462000 7101200	64 02	135 45
Mount Allan	105ϕ	9 441800 7018200	63 17	130 09
Keele Peak	105ϕ	9 435600 7036800	63 27	130 21
Hess River Syenite	105ϕ	9 406000 7050000	63 35	130 53
TG 6764	105ϕ	9 390200 7008000	63 12	131 11
Hi and Min	105I	9 455900 6960700	62 48	129 05
Two Buttes	105M	8 481200 7039300	63 29	135 23
West Ridge	115P	8 398500 7080500	63 52	137 04
Natlar River Plutons	105I	9 479200 6993200	63 04	129 25
TG 6688	105N	8 621700 7002800	63 08	132 35
O'Grady Stock	105I	9 506600 6973500	62 53	128 52
Mount Christie	105I	9 473700 6987400	63 01	129 33
Scheelite Dome	115P	8 437700 7073800	63 47	136 14
Emerald Lake	105ϕ	9 390000 7051000	63 35	131 13
Syenite Range	115P	8 387700 7094500	63 58	137 17
Tombstone Mountains	116B	7 615500 7147100	64 26	138 36

TABLE II Frequency distributions of tungsten in acid plutonic rocks

ppm W	Background plutons		
	McArthur Range	Mount Christie	Tombstones
< 1	93%	92%	75%
1 — 2	1	—	7
2 — 5	6	4	18
5 — 10	—	4	—
10 — 20	—	—	—
> 20	—	—	—

ppm W	Anomalous plutons			
	Potato Hills	Two Buttes	Mt. Allan	West Ridge
< 1	42	20%	80%	67%
1 — 2	8	7	4	13
2 — 5	8	20	—	8
5 — 10	8	26	8	8
10 — 20	17	7	2	—
> 20	17	20	6	4

Field program and results

During 1969 a trial program was undertaken with the aim of determining how the intrusives should be sampled, and whether significant geochemical differences exist between them. It was found that statistically meaningful results could be gained for unzoned intrusives if approximately 15 sites were sampled. At each site 2 samples were collected about 20 feet apart, this duplicate sampling allows the local as well as the overall variability to be determined, both quantities must be known if zoning is to be detected objectively. In many of the small intrusives (<3 squares miles) it was impossible to visit this minimum number of sites.

In larger bodies more than 15 cites were sampled in order that a sample density capable of detecting any major zoning could be maintained. Thus the ideal sampling program should ensure sufficient sample sites for statistically valid results and adequate sites for the definition of major zoning. In practice, this ideal scheme has to be modified by such factors as exposure and accessibility coupled with the time constraints of a regional sampling program (Fig. 2). Significant geochemical differences, unrelated to features such as the general acidity of the rocks, were found and on the basis of these a full scaled program was planned.

In the summer of 1970 a helicopter operation was mounted and 74 intrusives, or pluton clusters, were sampled within a 12,000 square mile block between 62°40′N and 64°40′N. This program involved sampling at some 1,100 sites, in addition the host rocks were sampled around many plutons in order that some geochemical control could be maintained. The samples were shipped to the Geological Survey of Canada laboratories in Ottawa where they are being analysed for a wide range of elements (Si, Al, Fe, Mg, Ca, Na, N, Ti, Mn, Ba, Cu, Pb, Zn, Co, Ni, Mo, W, U, Hg, Sn, Zr and Be).

Because of the significant amounts of Cu, Pb, Zn, Co and Ni that substitute in the silicate lattices of the major rock-forming minerals no attempt will be made to interpret these data before the major elements have been determined. However, some interpretation of elements such as Mo, W, U, Hg, Sn, Zr and Be can be made without that data. The data for Mo, W and U are complete and are presented as an interim report to illustrate the method. Mo and W were determined colorimetrically by zinc dithiol after an alkaline fusion and U was determined by fluorimetry after an HF-$HClO_4$ attack and preparation of a pellet by K_2CO_3 fusion.

Significant amounts of molybdenum and tungsten are present in acid rocks as molybdenite and scheelite or wolframite. Uranium is present in a variety of accessory minerals, particularly zircon and allanite.

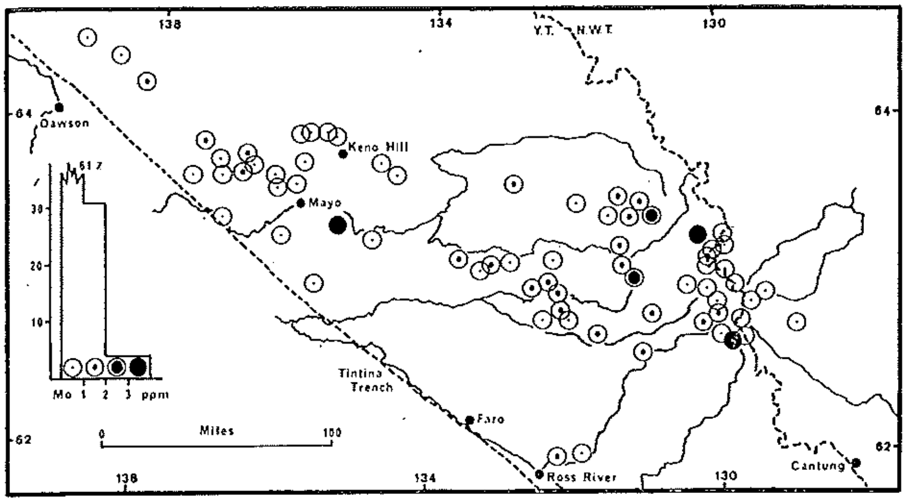


Fig. 3

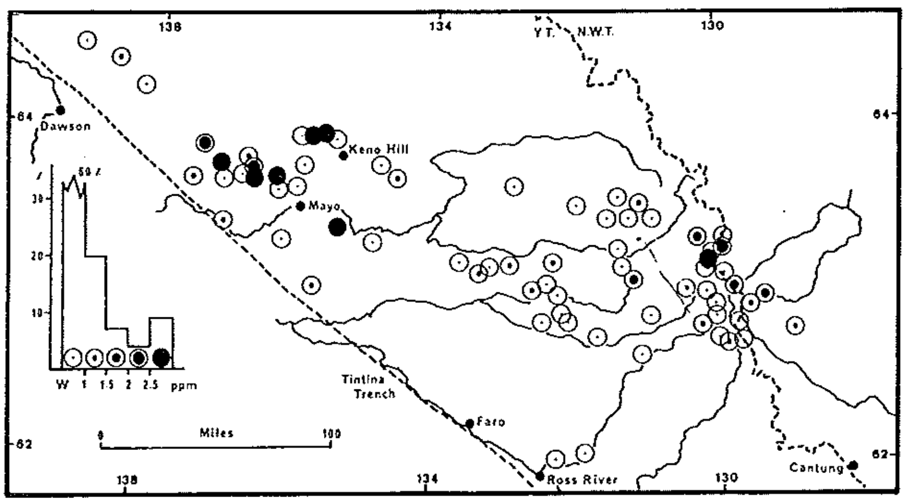


Fig. 4

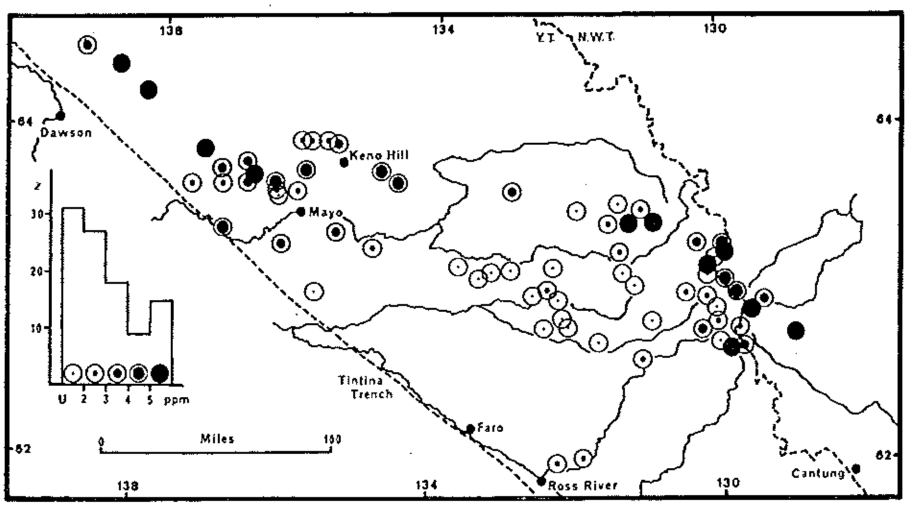


Fig. 5

Fig. 3 Mean molybdenum content of acid plutonic rocks

Fig. 4 Mean tungsten content of acid plutonic rocks

Fig. 5 Mean uranium content of acid plutonic rocks

For each of the 74 intrusives, the arithmetic mean and other summary statistics have been computed for molybdenum, tungsten and uranium. The data for the first two elements have been placed on open file by the Geological Survey of Canada (Garrett, 1971). Histograms have been prepared for the arithmetic means and the data grouped after inspection of these (Figs. 3, 4 and 5).

Much of the raw analytical data for molybdenum and tungsten have values less than the detection limits (0.5 and 2.0 ppm), and these samples have been given the values of 0.2 and 1.0 ppm. The result of this is that the histograms show a reversed J shaped distribution with some 60% of the means for both elements being below or equal to 1 ppm. However, that for tungsten is modified by the presence of a second population of means in excess of 2.5 ppm.

A similar shaped distribution is observed in mean uranium contents of the plutons. However, this is a real feature of the data as uranium was detected in all samples (limit 0.2 ppm) and there are only 3 mean values below 1 ppm. Like tungsten the distribution shows a second mode of pluton means in excess of 5 ppm. It is of note that the overall mean of the uranium data is 3.6 ppm, a value which compares well with the proposed 3.5 ppm for Shield rocks (Shaw *et al*, 1967) and a Clarke for acidic intrusives of 3 ppm.

During the following discussion a number of locations are mentioned. To avoid putting locations in the text, Table I contains details for all geographic points of importance.

The results for tungsten provide support for the theoretical model proposed in Fig. 1. Table II contains the frequency distributions for 7 plutons, 3 of which are background and 4 anomalous. In the case of the background plutons, there is very little, if any, data above the 5 ppm level and none above 10 ppm. In contrast, the anomalous plutons all contain more than 10% of the data above 5 ppm. With respect to Potato Hills, one of the so-called porphyry tungsten plutons (Cathro, 1969), 42% of the data is above 5 ppm. Mount Allan, which has only skarn mineralization associated with it, shows only 16% of the data above 5 ppm. In the light of the comments made with reference to Figure 1, it would appear that some level between 5 and 10 ppm is the critical value for identifying plutons possibly related to scheelite mineralization.

The areal distribution and histogram of the mean molybdenum in plutons are presented in Fig. 3. Only one contiguous area of higher mean molybdenum is outlined, this includes Keele Peak, the Hess River syenite and an unnamed peak TG6764 at the headwaters of the North McMillan river. Two isolated plutons with high mean content are the Hi and Min near which

Hudson Bay Mining and Smelting has its OMO claims and the Two Buttes stock. Two further plutons have isolated values in excess of 15 ppm and may be of interest, the first is Mount Allan where AMAX has a skarn tungsten deposit and the second is West Ridge at the headwaters of Left Clear Creek, which has produced considerable alluvial gold.

Two distinct areas of higher mean tungsten content are apparent on Fig. 4. The first contains only one pluton of the second population, the Mount Allan stock, and extends from a group of plutons on the north bank of the Natlar river in the Northwest Territories, northwesterly to Keele Peak in the Yukon. In addition the peak TG6764 to the west of Keele Peak also has a similar mean, as does an isolated peak, TG6688, west of Fairweather Lake. In general, means in this area only exceed 1.5 ppm. However, all plutons contain values in excess of 7 ppm, and if this criteria is used 3 more plutons may be added, the O'Grady stock, Mount Christie and the main stock of the Itsi range. These plutons form a well-defined belt along the Yukon-N.W.T. border which terminates at Keele Peak in the north and is open ended in the south.

The second tungsten belt is irregularly shaped lying in an arc around Mayo and contains 6 plutons of the second mode, in addition, the general level of the means in this belt is in excess of 2 ppm. One reason for the general increase in means in the Mayo area may be the mode of occurrence of scheelite. In the Keele Peak-O'Grady belt scheelite occurs primarily in skarns where the plutons intrude favourable limey rocks. In the Mayo area not only skarns are present but there are in addition porphyry tungsten deposits such as Potato Hills and Scheelite Dome. The latter 2 plutons are members of the second mode and it is significant that they are associated with alluvial gold and scheelite deposits. The most anomalous pluton was Two Buttes, 30 miles southeast of Mayo where both high molybdenum and tungsten values were found, this may well be a new porphyry tungsten. The coincidence of high molybdenum and tungsten in the West Ridge pluton at the headwaters of Left Clear Creek leads to the suggestion that the gold and accompanying cassiterite and scheelite could have been derived from veins or veinlets associated with this pluton.

The most notable feature in the uranium data, Fig. 5, is the presence of higher mean plutons around the north and east edges of the Selwyn belt. Within this large area of increased mean content two zones are prominent; the first trends northwesterly from the O'Grady pluton in the N.W.T. to the Emerald Lake pluton in the Yukon, the second also trends northwesterly from the Syenite Range to the Tombstone Mountains. These two discrete zones contain the second population (>5 ppm) plutons. The interpretation of these features should be undertaken in the light of several points. Firstly, uranium tends to be higher in the more acidic rocks, e.g. true granites and syenites, secondly it tends to be concentrated in zircons, and thirdly some polymetallic hydrothermal mineral deposits contain uranium as an important trace element.

A full interpretation must await the availability of major element and zirconium data. However, it may be of significance that many of the plutons of the McMillan Pass tungsten belt have a high mean uranium content, >4 ppm, and all those in the belt are >3 ppm. This feature is not apparent in the Mayo belt and could reflect the differing genesis of the scheelite mineralization, i.e., skarn deposits versus veins and veinlets. If a more positive link between the uranium and tungsten deposits of the McMillan Pass belt can be established uranium could prove to be a useful pathfinder element as analyses can be carried out more cheaply and uranium data does not have the extreme variability so often observed with tungsten.

All three elements show broad regional patterns and those for molybdenum and tungsten are in some cases related to known mineral occurrences. All the major tungsten showings of the sampled area were outlined in the program indicating the viability of the technique as a regional exploration tool. Several local areas of high molybdenum and tungsten were not previously recognized and warrant attention. The patterns for uranium are more complex and are related to rock type and broader regional features related to the chemistry of the crust.

Conclusions

In conclusion, it may be stated that regional rock sampling programs provide valuable geochemical data in the Selwyn Terrane of the Yukon and Northwest Territories. The main essential to this kind of program is that careful attention should be given to the sampling. The technique is not aimed at finding individual mineral deposits but rather at rejecting ground as not warranting further expenditure at some degree of confidence. The interpretation of the remaining trace elements will be more complex, involving a variety of statistical aids in an attempt to divide the data variability between rock type and other superimposed features, some of which may have an economic significance. Eventually, it will have to be determined if the methods developed in the Selwyn Terrane are applicable elsewhere, e.g. in other parts of the Western Cordillera, in other Cordilleran-like belts such as the Appalachian in Eastern Canada and finally on the Canadian Shield. The possibilities should be promising if the processes which formed skarn, hydrothermal vein and porphyry type deposits have remained constant with time. □

References

Cathro, R. J. (1969) Tungsten In Yukon, Western Miner, 1969, No. 4, pp. 23-28

Garrett, R. G. (1971) Molybdenum and Tungsten in some Acidic Plutonic Rocks of Southeast Yukon Territory, Geological Survey of Canada Open File Report 51, 5 p.

Shaw, D. M., Reilly, G. A., Muysson, J. R., Pattenden, G. E. and Campbell, F. A. (1967) An Estimate of the Chemical Composition of the Canadian Precambrian Shield, Can. Jour. Earth Sci., Vol. 4, No. 4, pp. 829-873.

The nickel potential of serpentinized ultramafic rocks

By O. R. ECKSTRAND*

■Considerable interest was stimulated in 1970 in the possible nickel potential of low grade serpentinite bodies, mainly because of the results of Dumont Nickel Corporation's exploration program. Relatively little has been published on the distribution of nickel in this type of rock. The previous lack of exploration interest probably stems from the commonly held belief that serpentinites have only a uniform, low nickel content of about 0.2 percent, and that this nickel is contained in the silicate, serpentine. By contrast, most of the producing nickel sulphide deposits associated with ultramafic bodies are marginal lenses of massive or heavily disseminated nickeliferous sulphide. The main purpose of this paper is to point out that some serpentinite bodies contain internal zones of sparsely disseminated, nickel-rich sulphides with grades significantly greater than 0.2 percent, such zones should be viewed as legitimate

*Geological Survey of Canada, Ottawa.

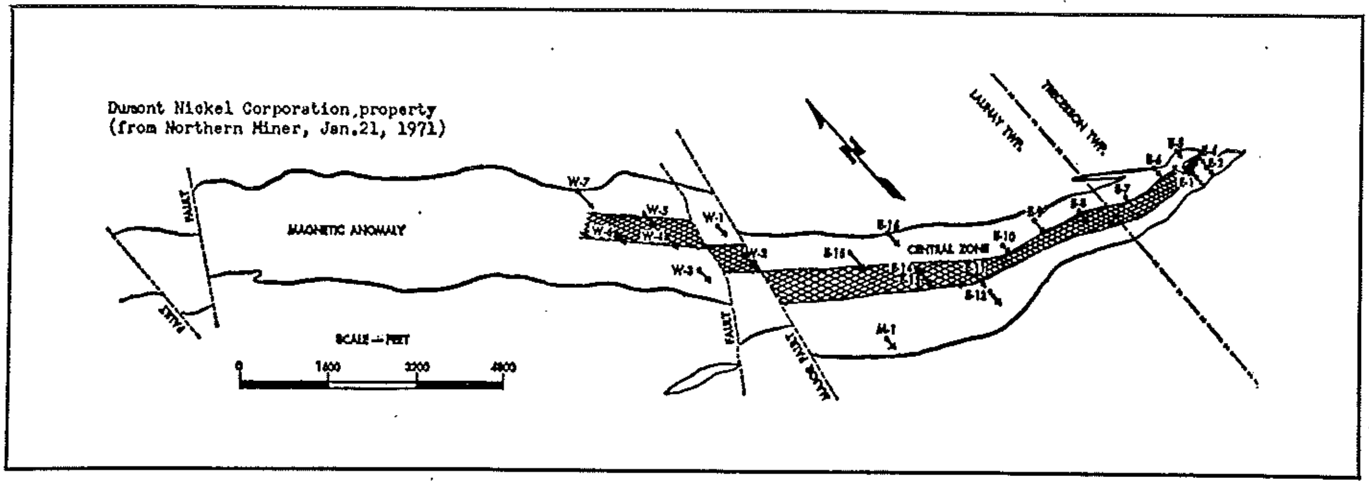


Fig. 1 Magnetic anomaly of the serpentinite on Dumont Nickel property, near Amos, Quebec

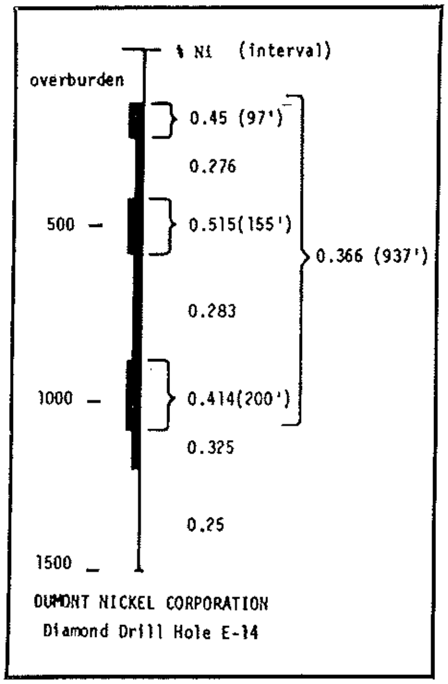


Fig. 2 Zoning of nickel content in the Dumont Nickel Corporation serpentinite

Mineral	Ni Content	Amount of mineral present
Pentlandite ($(Fe,Ni)_9S_8$)	26% (36-44)	Often present < 1%
Heazlewoodite (Ni_3S_2)	73%	Often present < 1%
Awaruite (Ni_3Fe)	69%	Usually present < 1%
Magnetite	Up to 1%	2 - 5%, approx.
Chromite	About 0.1%	trace to 3%, approx.
Serpentine	Less than 0.07%	95%, approx.

Fig. 3 Principal nickel bearing minerals identified to date in samples of Dumont material using X-ray and electron probe methods of identification

targets for exploration. Furthermore, it will be shown that the sulphides can occur in more than one textural habit, with important implications for metallurgical recovery.

This paper is based on some preliminary laboratory work done on samples from Dumont Nickel Corporation's serpentinite west of Amos, northwestern Quebec, and on published information from that and other nickeliferous serpentinites. I wish to express my thanks to Mr. George H. Dumont for drill core samples and related information.

Description of occurrences

The first serpentinite to be discussed is the one under active exploration by Dumont Nickel Corporation. Figure 1 shows the outline of the magnetic anomaly associated with the serpentinite body that is being explored. The body appears to be a conformable lens four and one half miles long and about one half mile wide, enclosed in andesitic volcanic rocks. It strikes northwesterly, and drill information suggests that it dips steeply to the northeast. The rock is a serpentinized dunite, and close packed pseudomorphs of one to two millimeter olivine crystals are clearly visible in most of the samples collected. Clinopyroxene is common in what appears to be a periodotitic border zone.

The central cross-hatched band in the diagram is the main mineralized zone of interest. It was reported in the November 17, 1970 issue of the Northern Miner to contain 224 million tons averaging 0.3 percent nickel or better. Subsequently reported drill results appear to have augmented both tonnage and grade. Assay information supplied by Dumont Nickel Corporation indicates that nickel content in the outer zone ranges from about 0.1 to about 0.25 percent.

Within a part of the 0.3 percent core zone, it is reported that assays in three adjacent holes seem to indicate the existence of at least three zones averaging 0.4 to 0.5% nickel and averaging about 150 feet in intersected width. Figure 2 shows a sketch prepared from published figures of these higher grade intervals in drillhole E-14. Furthermore, there are within the 0.5% zones, reported intervals of still higher grade. One such interval is said to average 0.91% nickel over 40 feet.

Figure 3 shows the principal nickel bearing minerals that have been identified to date in samples of Dumont material using X-ray and electron probe methods of identification. The most nickel-rich minerals are the sulphides, pentlandite and heazelwoodite, and the nickel-iron alloy, awaruite. Pentlandite in general has a nickel content of 36 to 44 percent (Graterol and Naldrett, 1969) but pentlandite in one Dumont specimen contains about 26 percent nickel (D. C. Harris, Mines Branch). Both magnetite and chromite contain minor amounts of nickel. In several determinations made on serpentine with the electron probe, nickel could not be detected. The detection limit of the probe was estimated at 0.07 percent.

Since the rock is about ninety to ninety-five percent serpentine, it appears that, of the total 0.3 percent nickel, the maximum proportion that could be in silicate form is about one quarter. The remainder must occur mainly as nickel sulphide and nickel-iron alloy, a fact that is highly significant for attempted metallurgical recovery. Note that no iron sulphides have been identified. Native copper has been reported in both megascopic and microscopic observations, but copper minerals are mostly lacking in the specimens examined to date.

A reconnaissance study of textures indicates that grain size of nickel sulphides and alloy falls in two distinct ranges, fine and coarse.

The fine sulphide and alloy particles shown in Figure 4 have a maximum grain size of about one micron and are rather uniformly dispersed through ser-

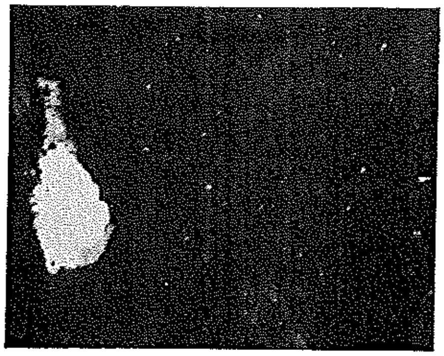


Fig. 4 Photomicrograph of fine sulphide and alloy particles in serpentinite (see text). The large grain of awaruite is approximately 0.05 mm. or 50 microns long. (Reflected light)

Fig. 5 Photomicrograph of coarse, composite pentlandite-magnetite-awaruite grains in serpentinite. The largest grain is 1.0 mm. long (Reflected light)

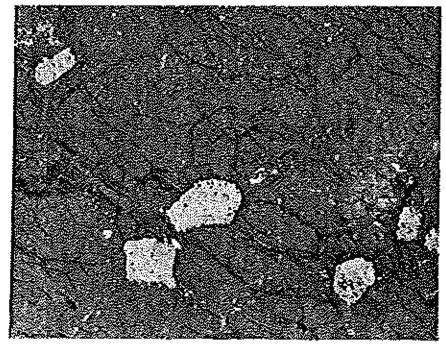


Fig. 6 Photomicrograph of coarse, composite heazlewoodite-magnetite-awaruite grains in serpentinite. The largest grain is 1.2 mm. long. (Reflected light)

pentine pseudomorphs of olivine crystals. In other specimens the size ranges up to perhaps five microns. These fine grains are present in essentially all specimens.

Figure 5 shows the characteristic habit of the coarse-grained sulphides and alloy. This specimen is unusually rich in sulphide grains, but their shape is typical, and they consist of an intergrowth of pentlandite, magnetite, and awaruite, in that order of abundance. The composite grains characteristically occur interstitially between olivine pseudomorphs; however, in some instances they are also encountered in cross-cutting fractures. In Figure 6, the composite sulphide grains have essentially the same texture as in the previous figure, but in this case consist of heazlewoodite, magnetite and awaruite. In none of the specimens examined so far have both pentlandite and heazlewoodite been recognized.

In contrast to the fine grains which occur in all specimens the coarse grains appear to have a systematic variation in distribution. They are essentially absent in 0.2% material; present as sparsely scattered grains in 0.3 percent material; and present in significant quantity in 0.5 percent material.

The second group of ultramafic bodies to be considered is a series of asbestos-producing serpentinites in Quebec's Eastern Townships, which have been studied by E. H. Nickel (1959) and J. A. Chamberlain (1966). These bodies average about 0.25 percent nickel, and the nickel-rich minerals which account for approximately one half of the total nickel are heazlewoodite and awaruite. Pentlandite was not reported. From the published descriptions it appears that there is in these bodies, also, a tendency toward two ranges of grain size, similar to those of the Dumont material.

The third and final serpentinite to be considered is the one on the Texmont property south of Timmins, which is reported in the 1970-71 Canadian Mines Handbook to contain 3.8 million tons averaging 1 percent nickel to a depth of sixteen hundred feet. According to descriptions given by Pyke and Middleton (1970) this mineralization occurs as two zones of finely disseminated sulphide, within a serpentinized ultramafic lens. The principal sulphide is said to be pentlandite, and no copper is mentioned.

Discussion

On the basis of these descriptions I would like to make some observations and interpretations. I consider that the Texmont, Dumont, and Eastern Townships serpentinites have enough characteristics in common that they can be considered to belong to the same class of nickel mineralization. This implies that there exists a class of nickel deposits with size and grade ranging from several hundred million tons of 0.3 percent nickel, to four million tons of one percent nickel. The deposits occur as zones within serpentinite lenses, and may tend to be central rather than marginal. In view of their size, and the recent evolution of low cost mining methods for large tonnage, low grade deposits, these occurrences offer obvious attractions.

Compositionally this type of nickel deposit appears to be characterized by nickel-rich sulphides, and virtual lack of pyrrhotite or pyrite. Copper content appears to be low. Presence of the nickel alloy awaruite may be common. It is not clear what sort of precious metal content there may be.

As regards nickel grade itself, there appears to be a general progression from Eastern Townships (0.25 percent), through Dumont (0.3 — 0.5 percent) to Texmont (1.0 percent); this is accompanied by the progression in sulphides from heazlewoodite, through heazlewoodite plus pentlandite, to principally pentlandite. Consequently, it would seem that pentlandite is the more favourable nickel sulphide despite the fact that it has a lower nickel content than heazlewoodite.

The most important factor in establishing viability in the higher grade members of this class of deposits will be to demonstrate sufficient tonnage. In the low grade deposits, metallurgical recovery will be the most important concern. In low grade material the fact that most of the nickel may occur in sulphide or alloy form is obviously advantageous for its possible recovery. However, this advantage may be seriously offset by extremely fine grain size. On the basis of textures in the Dumont and Eastern Townships serpentinites it is likely that recovery will improve with increase in proportion of coarse grained sulphide, and therefore with increase in grade.

Certain tentative interpretations regarding origin of these sulphides and nickel-iron alloy seem to be justified. Both Chamberlain and Nickel concluded that fine-grained heazlewoodite, magnetite and awaruite in the Eastern Townships ultramafic rocks were products of serpentinization. This interpretation appears valid for the Dumont serpentinite as well, and it would appear that the fine sulphide and alloy particles disseminated through olivine pseudomorphs represent nickel that was originally contained in olivine.

Some serpentinites are thoroughly recrystallized, so that olivine pseudomorphic textures are destroyed. It would seem logical to keep in mind the possibility that the fine-grained sulphides, too, may be recrystallized, and more favourable texturally for recovery.

Returning to the texture of the coarse grained sulphide in Dumont serpentinite, shown in Figures 5 and 6, I would like to suggest that these composite grains of nickel sulphide, magnetite and awaruite represent recrystallized primary magmatic sulphide "blebs" that were interstitial to close-packed olivine grains. A photomicrograph of a texture from the Muskox intrusion that is essentially identical with these has been published by Chamberlain (1967, Figure 38). However, in it, the silicate is completely fresh olivine, and the sulphide "bleb" consists of almost pure pyrrhotite and minor chalcopyrite. Had that sulphide "bleb" had a certain amount of nickel rather than copper, the Muskox assemblage and texture could have been an exact precursor to the Dumont material.

According to this interpretation the observed sulphur content of the serpentinite may have been derived entirely from pre-existing magmatic sulphides. Consequently there is no need to seek a source of sulphur outside the ultramafic body.

Further analytical and textural investigation of Dumont samples, presently in progress, will help to substantiate or modify these interpretations.

Exploration guide lines

One of the first factors to consider in an exploration program for this type of deposit is the known distribution of ultramafic rocks. It is not clear which of these intrusive bodies might be the most favourable. Judging by the Texmont and Dumont occurrences, the undifferentiated ultramafic lenses enclosed in Archean volcanics would seem the most encouraging. Serpentinization would be a common, though perhaps not essential, characteristic.

Another possible aid in selecting favourable ultramafic bodies may be the geochemical method recently proposed by Cameron, Siddeley and Durham. In this method, one determines the amount of Ni, Cu, and Co that can be leached out of bedrock samples of ultramafic rocks, using a hydrogen peroxide and ascorbic acid solution technique. The total of these metals, each multiplied by an appropriate factor can be used as a favourability index, such that a total greater than a certain threshold value would be considered indicative of favourable potential. This threshold value was determined in their study using traditional nickel deposits of the massive or heavily disseminated sulphide types. Consequently the same threshold value will probably not be directly applicable to the low grade type of deposit under consideration here. However, there is some indication that the method could be useful in a slightly different way.

In a few preliminary determinations, Dumont material grading about 0.2% total nickel gave 50 to 100 ppm of ascorbic acid leachable nickel, while material grading about 0.3% gave 200 to 400 ppm, or about 4 times as great an amount of leachable nickel. This more than proportionate increase suggests that the ascorbic acid leachable nickel might be more closely correlative with recoverable nickel, than with total sulphide. Obviously more work is needed to evaluate applicability of the method to these deposits.

It has been suggested for certain nickel deposits that sulphurization of the ultramafic body's silicate nickel is the process which gave rise to the orebodies, and that sulphide-rich wallrocks were the source of sulphur. If primary sulphides in the ultramafic body are the source of sulphur, as suggested here by textures in the Dumont serpentinite, then perhaps exploration programs need not consider sulphide-rich wallrocks as a necessary characteristic.

In conclusion, I submit that low grade nickeliferous serpentinites of the type described herein, constitute a potential source of nickel worthy of serious exploration efforts.

References

Cameron, E. M., Siddeley, G. and Durham, C. C. (in press): Distribution of ore elements in rocks for evaluating ore potential; Nickel, copper, cobalt and sulphur in ultramafic rocks of the Canadian Shield. Proc. IIIrd Internat. Geochem. Symp., Toronto, April, 1970, Can. Inst. Mining Met. Spec. Vol. II, "Geochemical Exploration"; also available as Geol. Surv. Can. Open File Rept. 35.

Chamberlain, J. C. (1966) Heazlewoodite and awaruite in serpentinites of the Eastern Townships, Quebec. Can. Mineralogist, Vol. 8, Part 4, pp. 519-522.

Chamberlain, J. C. (1967) Sulfides in the Muskox intrusion. Can. J. Earth Sci., Vol. 4, pp. 105-153.

Graterol, M. and Naldrett, A. J. (1969) The mineralogy of the Marbridge No. 3 and No. 4 nickel-iron sulfide deposits. Preprint of paper presented at MAC/GAC meeting, Montreal, June, 1969.

Nickel, E. H. (1959) The occurrence of native nickel-iron in the serpentine rock of the Eastern Townships of Quebec province. Can. Mineralogist, Vol. 6, Part 3, pp. 307-319.

Pyke, D. R. and Middleton, R. S. (1970) Distribution and characteristics of the sulphide ores of the Timmins area. Preprint of paper presented at C.I.M.M. convention, Toronto, April, 1970.

Till studies and their application to regional drift prospecting

By W. W. SHILTS*

Till as a sediment

■ Glacial till is an unsorted, heterogeneous sediment composed of material eroded from sources a few inches to hundreds of miles from its point of deposition. There is no general agreement as to which textural parts of till are indicative of long-distance transport and which parts reflect only short transport, if, indeed, any such generalization may be made.

Two principal modes of deposition of till can be demonstrated. The first mode is lodgment or plastering of till onto bedrock at the sole of a moving body of ice. The second mode is the release of debris onto the the lodgment facies by slumping at the edge of a glacier. The latter process contributes to end moraine formation where the ice edge is static for a period of time or forms blankets of varying thicknesses of sandy till released from the glacier as it melts away. This till facies has been referred to as ablation till and is usually sandy with irregularly distributed pockets of water-laid sediments.

Till is the most poorly sorted of sediments. It contains particles ranging from colloidal size to fragments whose volume may be measured conveniently in cubic miles. Usually, analyses of till composition are made on limited portions of the textural continuum. Since the late nineteenth century, when till was finally universally recognized as a glacial deposit, frequencies of rock types in the boulder and pebble fraction of till have been extensively used in drift prospecting and in tracing directions of glacial transport. From the 1930's, to the present, mineral composition of the finer sand fractions of till has been used for similar purposes. In the 1940's, with the rapid improvement of analytical tools, such as the X-ray diffractometer and various "rapid" chemical analyzers, the finest fractions of till, silt and clay, began to be analyzed to determine their mineralogic and chemical composition in order to define source areas and directions of glacial flow.

Problems in studying dispersal of till components

The most serious constraints on using glacial till as drift prospecting medium are: (1) the lack of understanding of modes of till deposition; and (2) the analytical problems created by the extreme compositional variation from coarse to fine particle size in till.

The first constraint usually manifests itself in the difficulty of distinguishing ablation facies from lodgment facies. Particles which ultimately form ablation till are carried in the higher parts of a glacier, and not at its sole. With respect to lodgment till, they tend to be less abraided and to reflect the complex flow patterns of the late stages of glaciation, when ice is thin and easily diverted by topographic obstructions.

Textural control of till composition is probably the most serious problem facing the individual who wishes to use till as a prospecting medium. A till sample can generally be broken down into four major texture/composition, particle-size classes (Fig. 1):

*Geological Survey of Canada

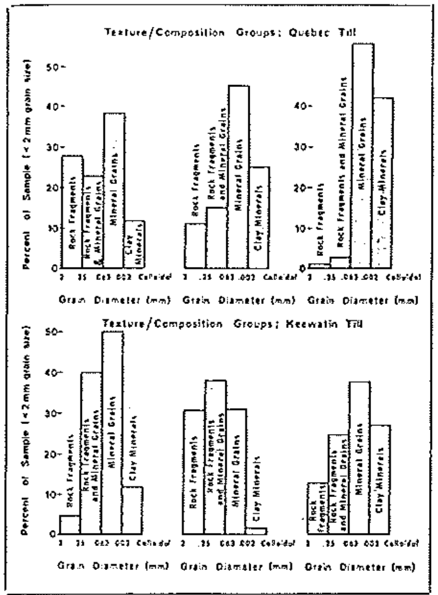


Fig. 1 Typical variations of texture/composition classes in tills of Quebec and Keewatin. Note extreme variation of clay which holds most of the extractable cations

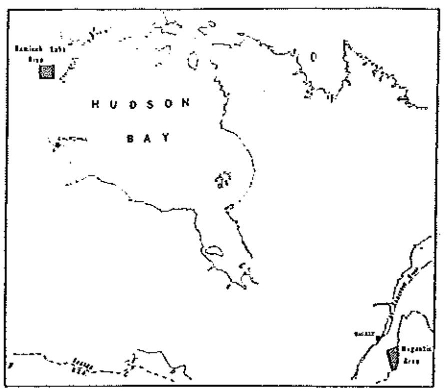


Fig. 2 Location of study regions

1. *Coarse fraction*: size range from largest boulders to 60 mesh (0.25 mm); particles are almost 100% rock fragments with occasional vein quartz, vein calcite, or coarse feldspar grains.
2. *Fine sand fraction*: <60 mesh (0.25mm), >230 mesh (0.062mm); this fraction contains a mixture of rock fragments and monomineralic particles. The bulk of the fraction is quartz, calcite, and feldspar, but rock fragments may comprise 40% to 60% of the coarser grades, and heavy minerals 2% to 20% of the total fine sand.
3. *Silt fraction*: <230 mesh (0.62mm) $>2\mu$ (0.002mm); this fraction is composed of monomineralic grains which are predominantly quartz, calcite, and feldspar. "Heavy" minerals comprise 2% to 15% of the fraction.
4. *Clay fraction*: $<2\mu$ (0.002mm)-colloidal size; this fraction is composed mostly of clay and other micaceous minerals with minor amounts of quartz, feldspar, calcite and other minerals. It also contains aggregates of clay-size iron and other oxides and varying amounts of non-crystalline colloidal material.

The mineralogical and chemical composition of each class is radically different from the other three, and the relative proportions of the classes may vary significantly over a study region (see Fig. 1). Therefore, it is imperative that the relative contributions of minerals and elements from each class be known when several classes are combined for analysis. Alternatively, a single class or portion of a single class should be used exclusively in analyses.

The clay fraction is the most critical fraction in interpreting chemical analyses of tills. It is the active portion of till in that it has a high exchange capacity for ions present in groundwater and is most susceptible to weathering and leaching during the process of soil formation. For these reasons, the clay fraction, of all the fractions in till, is most likely to reflect post-depositional processes (either ion concentration or leaching) which are entirely unrelated to its original composition. It will be shown later that when the silt and clay fractions are analyzed together, as is commonly done in geochemical studies, apparent cation concentration is strongly dependent on the amount of clay in the sample analyzed.

Study regions

Dispersal patterns for several components of till have been studied in two regions that differ radically in topography, bedrock type, climate and age of till (Fig. 2). In both regions, long distance transport for at least part of all textural grades studied has been demonstrated, and many phenomena that have hitherto hindered the use of till as a prospecting medium have been defined.

Lac-Mégantic, Quebec

The Lac-Mégantic study area is located in the folded Appalachian region of southeastern Quebec. Most of the area is underlain by slightly metamorphosed, Ordovician- to Devonian-age slates and impure sandstones which are cut by acid igneous plutons and gabbroic, basic volcanic, and ultrabasic bodies of the Thetford Mines-Asbestos complex. The area lies southeast of the main spine of the Green-Sutton-Notre Dame mountains and is bounded on its southeast side by the Boundary Mountains. The terrain is gently rolling but is broken by several high, isolated peaks formed on the igneous intrusions. During the early and late stages of the last glaciation, these peaks caused radical divergence of glacier lobes from the east-southeast direction of flow that predominated at the height of glaciation (McDonald and Shilts, 1971).

Till in the Lac-Mégantic region is generally compact, grey, weathering-brown, calcareous sediment containing subequal amounts of clay, silt, and sand and few clasts larger than one foot in diameter. The till surface is mantled by large boulders thought to represent the ablation mode of deposition. In unweathered samples the clay fraction is composed largely of well-crystallized chlorite and white mica with no detectable expansible clays and little colloidal material; in weathered samples, chlorite is broken down to varying degrees to expansible minerals and iron oxide is abundant in colloidal form. As the expansible minerals and iron oxides were thought to increase the potential of weathered till to concentrate cations, only unweathered samples were analyzed for trace elements.

Dispersal patterns

Of the several till components studied in the Lac-Mégantic area, the dispersal patterns of those derived primarily from the Thetford Mines-Black Lake ultrabasic-gabbroic complex will be discussed. Figure 3 depicts the dispersal pattern of ultrabasic and gabbroic boulders in the Lac-Mégantic area. The boulders were collected from the surface ablation mantle and not from within the till matrix. The highest concentrations form narrow fingers extending southeast from the ultrabasic terrane and not fans as are often depicted on glacial dispersal maps. There is also an area of low ultrabasic-gabbroic concentration in the lee of the Little Mégantic Mountains. This gap is partially caused by blocking of ultrabasic debris by those mountains.

Figure 4 shows the dispersal pattern for chromium determined spectrographically on the <230 mesh (<0.062mm) fraction of till. Chromium has a dispersal pattern remarkably similar to the surface boulder pattern and can be traced at least 40 miles down-ice from the presumed source. Sand-size magnetite concentrations and nickel in silt and clay (no figures) have dispersal patterns essentially identical to chromium.

Because of certain consistent variations in concentrations of copper and zirconium, it was suspected that the amount of clay in the <230 mesh fraction had a partial influence on trace element distribution. Figure 5 shows the relationship of six trace elements studied to the amount of silt in the sample. Copper clearly decreases with increasing silt, and zirconium increases. Vanadium, titanium, chromium, and nickel all seem to decrease with increasing silt but have secondary, nearly vertical (tex-

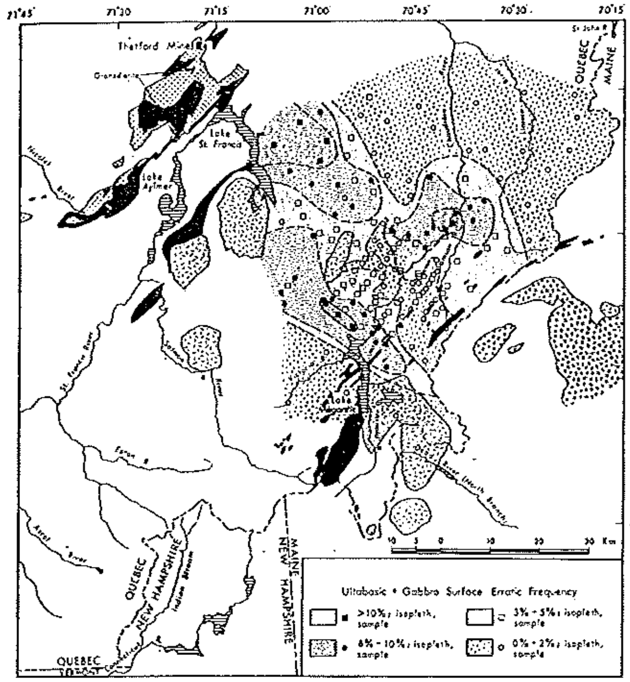


Fig. 3 Dispersal pattern of surface erratics originating in the Quebec ultrabasic belt; cross-hatched pattern represents ultrabasic and metagabbro outcrop

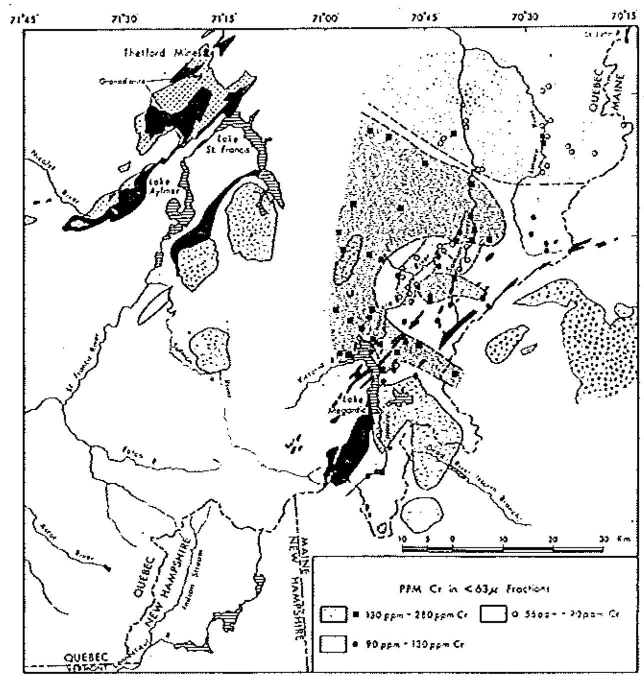


Fig. 4 Dispersal of chromium in silt-clay fractions of till, southeastern Quebec; cross-hatched pattern represents ultrabasic and metagabbro outcrop

ture independent) trends which corresponds to anomalies.

Summary

In the Lac-Mégantic region, dispersal patterns are ribbon or finger-shaped with some indication of narrowing in the down-ice direction. Dispersal bands can be detected up to 40 miles away from source areas. Trace elements, minerals, and boulders have comparable dispersal patterns and any of these components could have been used to locate an ultrabasic body similar to that at Thetford Mines. Trace element concentrations are influenced to varying degrees by clay content except in anomalous areas where trace element concentration seems to be independent of texture. With the sample split and analytical techniques used, anomalous values are 2 to 5 times higher than background values for chromium and 4 to 9 times higher than background values for nickel, but are low with respect to the average trace element contents of soils formed on ultra-basic rocks (Ni $\cong$ 1000 ppm; Cr $\cong$ 3000 ppm; Mitchell, 1964).

Kaminak Lake Area, District of Keewatin

In the summer of 1970, the Geological Survey undertook a pilot regional drift-prospecting project 240 miles north-northeast of Churchill, Manitoba, in the Kaminak Lake region of Keewatin (Fig. 2). The purpose of the first summer's work was to sample till over a large area with the objective of outlining transported anomalies which could serve as target areas for follow-up work in the summer of 1971.

The Kaminak region was chosen for several reasons, foremost among which were the apparently simple pattern of ice flow (southeast) (Lee, 1959) and the existence of semi-detailed maps of Archean-age volcanic and sedimentary strata which were known to contain several areas of sulphide mineralization (Davidson, 1970a, 1970b).

The Kaminak Lake area is a region with very low relief and extensive till cover. The entire area covered by the sample grids was submerged in the post-glacial Tyrrell sea, but marine sediments are thin and discontinuous over glacial deposits. Terraces and beaches, cut into glacial deposits as the sea receded, are common features of the landscape.

The Kaminak area is underlain by deep, continuous permafrost which thaws to depths of 3 to 4 feet in the summer. Surfaces underlain by marine sediments and till, both of which contain appreciable amounts of clay and silt, are characterized by numerous frost boils and solifluction lobes. Frost cracks and polygonal ground are confined to well-sorted, gravelly or sandy sediments with little or no silt and clay or to alluvial plains covered by organic mats. Because frost boils are usually restricted to the more poorly sorted sediments, of which till is the most common member, sample pits were dug in frost boils.

Sample traverses were laid out to take advantage of the known direction of ice flow. Samples were located at 0.8-mile intervals along lines oriented at right angles to the direction of ice movement. Spacing between lines was 4 miles, or 5 times the sample spacing along lines. At each sample site a 50cm- to 100cm-deep pit was dug and samples were collected from the walls of the pit.

Each sample was air-dried, sieved to <230 mesh (silt and clay), and analyzed for trace element content. Zn, Pb, Ag, and Mo were extracted by a hot, HCl-HNO_3 leach and analyzed by atomic absorption. Cu, Ni, and several other minor elements were analyzed by emission spectrography. Heavy minerals were separated in bromoform from the fine-sand grade of some samples. The heavies were crushed in a ball mill, leached in hot, mixed HCl and HNO_3, and analyzed by atomic absorption for Cu, Ni, Zn, Pb, and Ag.

Before investigation of the till composition of any region, it is necessary to have a fair understanding of regional stratigraphy so that sediment types encountered during sampling may be anticipated and recognized in sample pits. We were fortunate, in Keewatin, to have an easily accessible stratigraphic section which not only revealed at one place the sediments that were eventually encountered in sample pits, but also exposed the sediments in their frozen state so that their original characteristics could be studied without the disturbance, mixing, and weathering common to the active zone.

The Kaminak section (Fig. 6) consists of 4.5 m of till overlain by fine-grained, fossiliferous marine clay which grades upward into massive sandy silt

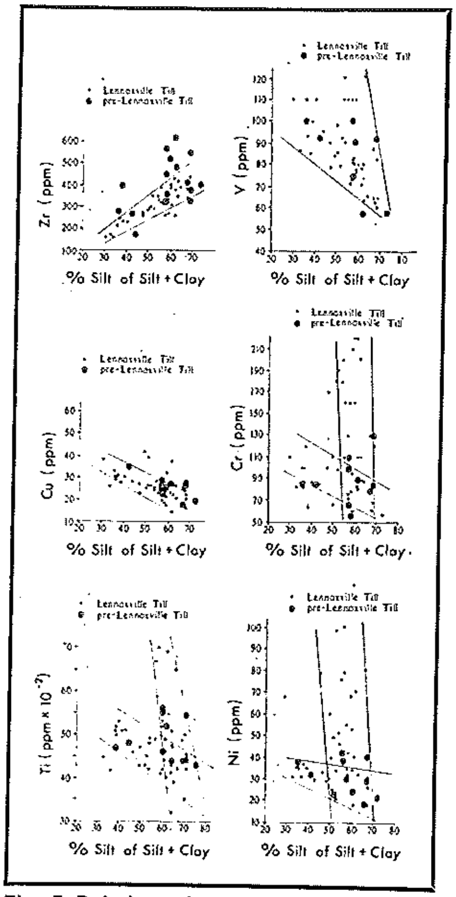
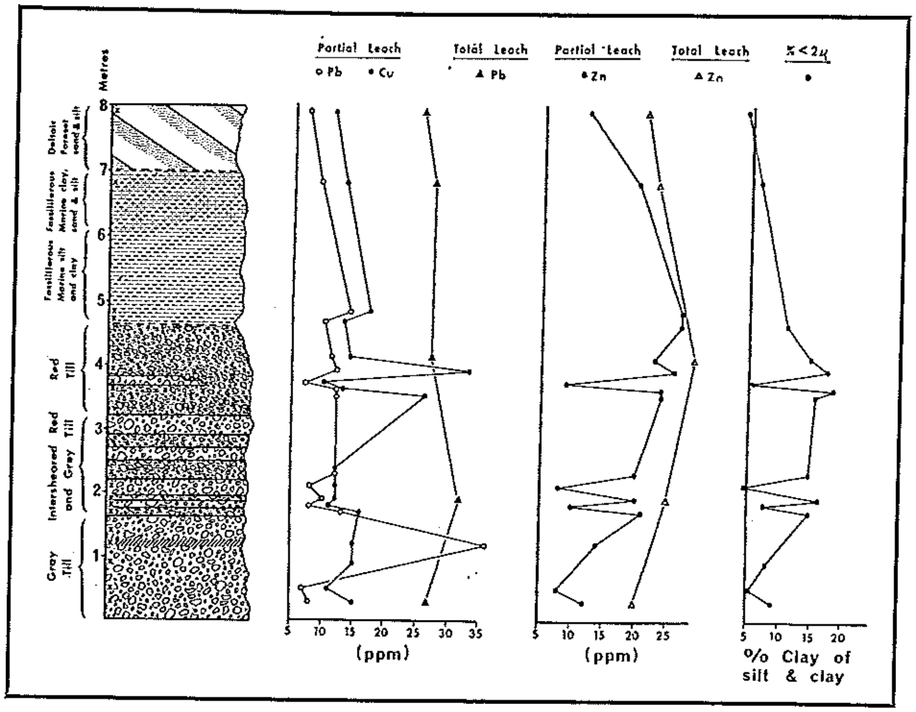


Fig. 5 Relation of trace element content of silt and clay to amount of silt in tills from southeastern Quebec. Bounding lines are arbitrary

Fig. 6 Stratigraphic units and trace element variations in section, Kaminank Lake, Keewatin. Trace element concentrations determined on silt and clay fractions of sediments. Note strong dependence of Zn and dependence of Cu and Pb on clay content



and sandy foreset and gravelly topset beds of a marine delta. The till consists of a lower, massive, sandy, grey unit which is covered by a zone of shear or thrust plates of alternating grey and brick-red till. The intersheared zone is overlain by massive red till.

The principal difference between the two types of till is that the red till has more clay than the grey. The clay of both tills is maroon because of adsorption and inclusion of colloidal iron oxides; the greater amount of this material in the red till accounts for the colour discrepancy. It was found, as in the Megantic area, that certain trace elements were concentrated in the clay-size fraction so that at this one site, trace element concentrations (particularly zinc) varied significantly. In sample pits, either one or the other type of till or, rarely, marine sediment, was encountered. Often, mixtures of the types occurred with discrete blocks of red till included in a grey, sandy matrix or vice-versa. Trace element concentrations showed even stronger disparities among sediment types in sample pits than in section (Table I). Therefore, for elements, such as zinc, that are preferentially adsorbed by clay minerals or colloidal oxides, the regional anomaly map is largely a sophisticated (and expensive) map of textural variation.

Figure 7 shows the texture-dependent relation of zinc for samples collected in the Kaminak area. No secondary spikes are evident such as were noted for Cr and Ni in the Mégantic area. Although Cu, Ni, Pb, and Ag have not yet been plotted against clay, qualitatively similar texture dependence is evident for these cations, although not to the degree of Zn.

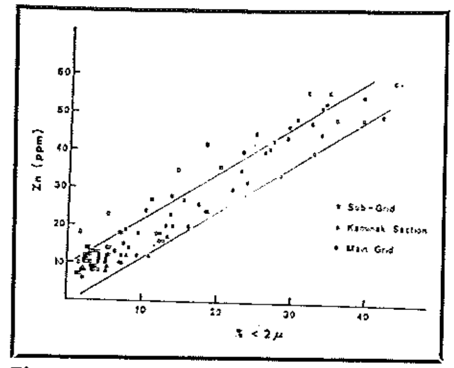


Fig. 7 Scatter plot of Zn concentration in silt and clay (<230 mesh) against clay content of tills from Kaminak Lake area. Cu, Pb, and Ag show similar, but less steep trends. Bounding lines are arbitrary

To avoid the textural problem where searching for small, transported anomalies, the chemically active clay portion of till and other quaternary sediments must be removed or its influence rationalized. To rationalize the influence of clay on Zn concentration, sample values may be adjusted by relating them to the slope of a best-fit line drawn through figure 7. This procedure is time-consuming because of the requirement for textural data; a better method of rationalization might be to normalize the data by relating cation concentrations to measured exchange capacities which are directly related to both the clay content and mineralogy of the clay fraction.

The author feels that an alternative, superior method of collecting cation data is to eliminate clay by elutriation or by analyzing a portion of the sand or coarse-silt fractions which can be segregated by simple dry sieving. A drawback of analyzing these fractions, as sieved, is that trace element values will be very low and near the detection limits of the analytical tools (note the projected Zn concentration at 0% clay on Fig. 7). However, by separating, crushing, and analyzing heavy minerals from the sieved fraction, trace element values are elevated above those of the silt-clay fraction and chances of post-depositional chemical changes are minimized.

Figures 8 and 9 show the relationship of Zn in silt-clay to the per cent of clay in the samples from a portion of the 1970 grid. Glacial movement was determined to be southeast from strong drumlin development and from striation orientation. Some striae were noted that cross the southeast striae and trend nearly due south.

Zn is strongly influenced by textural variations. A lead-zinc orebody that has been extensively drilled, but not developed, appears to serve as a focus for a

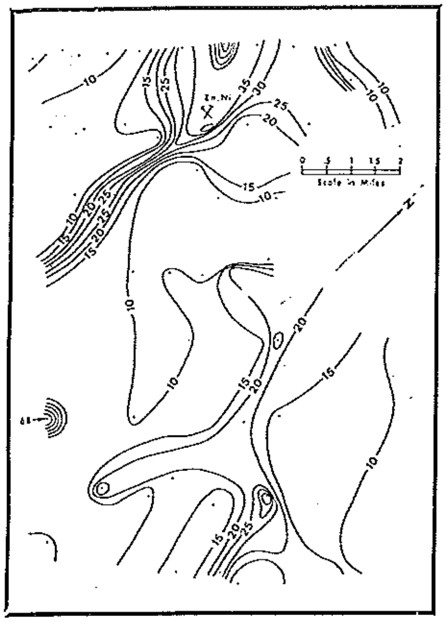


Fig. 8 Dispersal of Zn in silt and clay (<230 mesh) fractions of till-Kaminak Lake sub-grid. Contour interval = 5 ppm

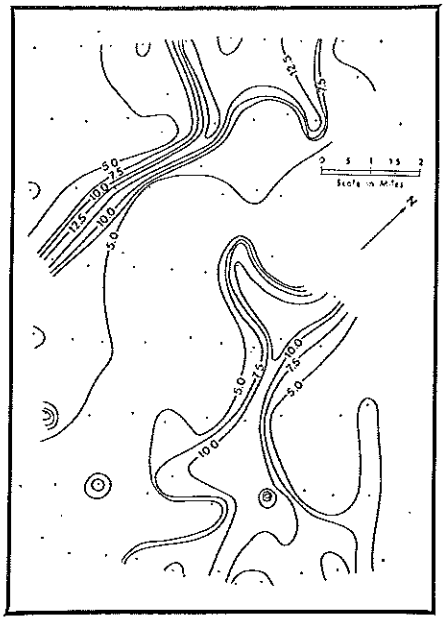


Fig. 9 Per cent of clay in <230-mesh fractions of till, Kaminak Lake subgrid. Pattern is similar to Zn dispersal as well as to Pb, Cu, Ni and Ag patterns (not figured). Contour interval = 2.5%

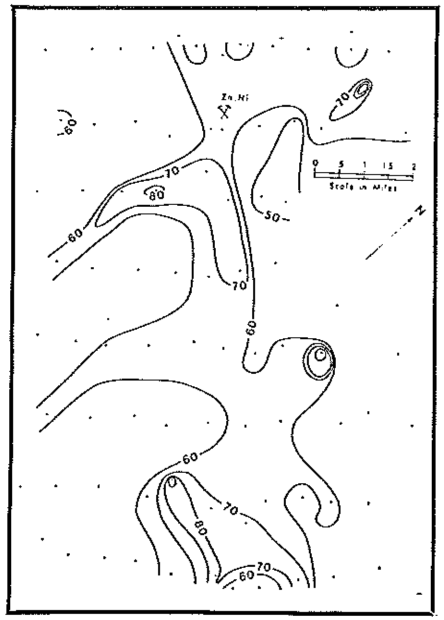


Fig. 10 Dispersal of Zn in heavy minerals (SG>2.85) of fine-sand fractions of till, Kaminak Lake sub-grid. Contour interval = 10 ppm. Note appearance of southeast trends predicted by southeast orientation of drumlins and striations

south-transported anomaly. Other anomalies appear to be related to unknown occurrences, but, again, most anomalies can be related to textural differences.

Figure 10 depicts Zn concentrations in crushed heavy mineral separates from the same samples as in figures 8 and 9. Zinc still shows the southerly trend but also shows the southeast trend expected from drumlin and striation orientations. Several clay-induced anomalies disappear and other anomalies appear. It is interesting to note that the convergence of south and southeast-trending zinc anomalies indicate a zinc enrichment at a point southeast of the drilled occurrence. The point of convergence is under a large lake.

An observation that may be made, after comparing silt-clay and heavy-mineral dispersal patterns of Cu, Ni, and Pb (no figures) to those of Zn, is that heavy-mineral anomalies for Cu do not follow the Zn-Pb-Ni anomalies as they do in the silt-clay analyses. That Cu follows the Zn-Pb-Ni anomalies in the silt-clay diagrams is a function of preferential adsorption of copper onto clay or colloids and not necessarily the affinity of copper for areas of Pb-Zn-Ni mineralization.

TABLE I Comparison of trace element contents of till matrix, weathered zones, and inclusions from single sample sites (in ppm)

				Heavy minerals	
Sample	Facies	Zn	Pb	Zn	Pb
210	Grey till	8	6	37	16
210A	Red till inclusion	77	18	38	22
132	Grey till	13	9	—	—
132A	Red till inclusion	73	20	—	—
134	Leached till	6	8	—	—
134A	Red till	30	19	—	—
136	Leached till	11	12	—	—
136A	Red till	40	20	—	—
119	Red till	36	20	—	—
119A	Grey till inclusion	7	8	—	—
211	Clayey red till layer	49	16	—	—
211A	Red sandy till	14	10	—	—
245	Leached surface layer	9	12	—	—
245A	Red sand	16	14	—	—
325	Composite till sample	9	10	—	—
325A	Leached horizon	10	8	—	—
325B	Red till inclusion	55	21	—	—

Conclusions

Although preliminary data have not yet been entirely evaluated, it appears that orebodies or bedrock sources of anomalous metal concentration can be located by outlining and defining transported anomalies. Because Kaminak till anomalies have relatively low values as compared to those developed by geochemical dispersion in the immediate vicinity of orebodies, the adsorptive power of widely varying amounts of clay tends to mask true anomalies and create false anomalies. At this point, some sort of preconcentration of the non-clay fraction of till (and all other unconsolidated sediments from glaciated terrain) seems to give the most realistic picture of glacial dispersal of mineralized fragments. Although abnormal cation concentrations have been detected as far as 40 miles from their source areas in Quebec, transport of cations over similar distances has yet to be firmly established for the Kaminak area — partially because of the uncertainty regarding the significance of the analyses of the clay-silt fractions obtained for the bulk of the samples. Finally, the author feels that regional analysis of drift transport of trace elements will be a most efficacious technique for prospecting in all glaciated terranes, once the proper combinations of sample split, preconcentration, processing ease, and data reduction are established. □

References

Davidson, A., 1970a, Kaminak Lake map-area, District of Keewatin; Geol. Surv. Can., Paper 69-51.
Davidson, A., 1970b, Eskimo Point and Dawson Inlet map-areas (north halves) District of Keewatin; Geol. Surv. Can., Paper 70-27, 21 p.
Lee, H. A., 1959, Surficial geology of southern District of Keewatin and the Keewatin ice divide, Northwest Territories; Geol. Surv. Can., Bull. 51, 42 p.
McDonald and Shilts, W. W., in press, Quaternary stratigraphy and events in southeastern Quebec; Bull Geol. Soc. America., vol. 82, no. 3.
Mitchell, Robert L., 1964, Trace Elements in Soils; in Bear, F. E., ed., Chemistry of the Soil, p. 320-368, Reinhold Publishing Corp., New York.

Relationship of mineralization* to stratigraphy in the Archean Rankin Inlet-Ennadai Belt

as compared with analagous "Greenstone" belts of the Superior Province

By R. H. RIDLER*

■In the summer of 1970 the author, working for the Geological Survey of Canada, initiated a study of the interrelation of the metallogeny and stratigraphy of the Rankin Inlet-Ennadai Belt in the south central District of Keewatin. This paper rests upon the data gathered in the short Arctic summer (Ridler, 1971) plus the excellent reconnaissance mapping of others, principally A. Davidson (1970 a, b) of the Survey. In addition the author has drawn upon experience gained from work in the Superior Province (Ridler, 1970 a, b) and the extensive literature available. Accordingly, he believes that the relations about to be presented are founded upon well documented geologic models (Goodwin and Ridler, 1970; Hutchinson, Ridler and Suffel, 1971), and hence will prove to be more fact than fiction.

General geology

The Rankin Inlet-Ennadai Belt is an assemblage of Archean supracrustal and plutonic rocks. It stretches 400 miles from the vicinity of Snowbird Lake in the southeast corner of the District of Mackenzie east-north-east to Hudson Bay at Rankin Inlet and is up to 100 miles wide, making the belt the second largest in Canada.

To the north, south and west the belt is bounded by terrains characterized by pronounced Hudsonian orogenic effects, and to the east by Hudson Bay and Paleozoic cover. Thus it differs by definition significantly from analogous belts in the Superior Province whose limits are set by a change in predominant rock type from volcanic to sedimentary, the traditional example being the Lake of the Woods or Keewatin belt which is bound on the south by Coutchiching schists and to the north by English River gneisses. It follows that, unlike the belts in the Superior Province, the margins of the Rankin Inlet-Ennadai Belt can be and in fact are discordant to major supracrustal lithofacies trends or, put more simply, the present outline and trend of the belt (E.N.E.) coincides only roughly with the trend (E.-W. to W.N.W.) of the original Archean basin.

Figures 1, 6, 7 referred to in this article are unavailable at time of publication. These remaining figures will appear in the May issue of CMJ.

The area of greatest interest for the current project is the north-east half of the belt as outlined on the original 16 mile reconnaissance map (Fig. 1) (Wright, 1967). For reference, the names of three well known mining camps in their correct spatial orientation are on the diagram. In addition, the specific area studied last summer in the vicinity of Kaminak Lake, and the traces of the two cross-sections sampled are indicated. For our purposes the most important geological feature revealed by the map is the overall geometry of the belt produced by domical plutonic complexes and circumferential Archean supracrustal rocks, all within fairly well defined limits. Resolution of the various Archean supracrustal rocks was not possible at this scale. By way of comparison, the south-west portion of the Abitibi Belt, drawn at the same scale, (Goodwin and Ridler, 1970) shows a great deal of structural and petrologic variety, in particular, vast amounts of economically favourable felsic volcanics, porphyries, sediments, and iron formation. The four mile mapping programme of the Survey has proven the existence of a similar diversity of rock types in the Rankin Inlet-Ennadai Belt (for bibliography see Davidson, 1970 a, b).

Method and justification

Clearly, the belt presented an excellent opportunity to apply the technique of volcanic stratigraphic analysis found to be so effective in the Archean rocks of the Superior Province at, for example, Sturgeon L., Uchi L. and of course Noranda among others. Another very attractive aspect was the chance to put the author's possibly heretical ideas on Archean metallogeny (Ridler, 1970 b; Hutchinson, Ridler and Suffel, 1971) to the acid test in an area lacking mines but possessed of excellent outcrop.

In particular the project involves two studies:

First, the volcanic stratigraphy is studied and sampled along cross-sections. The samples are submitted for chemical analysis, to aid in identification and thus establish the trend of volcanic differentiation. By careful field examination of primary rock textures along the lines and in critical areas, detailed structure is established. By this method the areas of greatest thickness, variety and differentiation are located (Fig. 2).

Second, in a region lacking mines, the obvious target for metallogenic study is the regional iron formation. By tracing the various facies into one another and establishing their areal distribution a model for the original basin can be established. In addition, significant Fe, Au, or base metal mineralization may be found. An example is the south margin of the Abitibi Basin where facies change from oxide to the south, through carbonate, to sulfide to the north (Ridler, 1970 a, b).

Other known mineralization is also studied in order to gain an understanding of its relation to stratigraphy. Ni associated with mafic and ultra-mafic volcanics is perhaps the best example, but Au associated with porphyries has historically been important.

The two approaches are then integrated, and areas exhibiting the greatest coincidence of favourable relations designated. Examples in the Abitibi Belt are the Timmins, Noranda, or Kirkland Lake camps. Each combines great volcanic thickness and variety, a high degree of differentiation and diverse iron formation.

Aspects of the geology of the Kaminak Lake area

The Kaminak Lake area was chosen for study because reconnaissance 4 mile mapping by the Survey has established many of the above prerequisites, and both access and outcrop are excellent. Fig. 3 is an integration of David-

*Geological Survey of Canada.

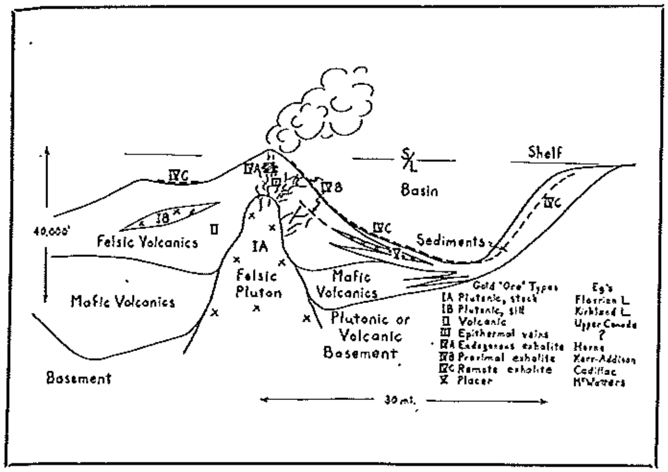


Fig. 2 Archean Volcano-Sedimentary Complex

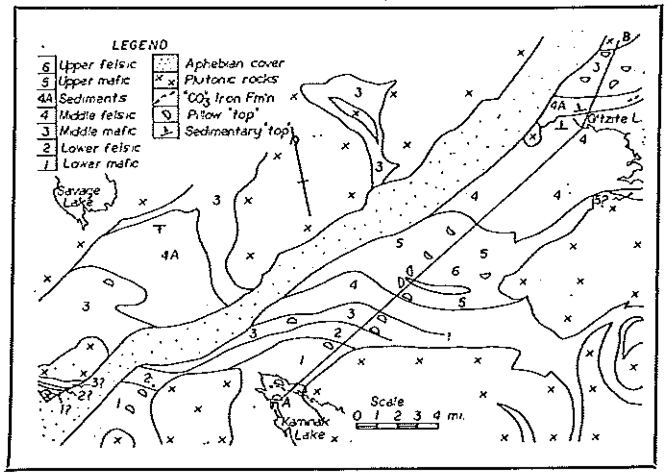


Fig. 3 Geological sketch map, North Kaminak Lake

son's (1970 a) and the author's (1971) last summer's work. The volcanic and sedimentary stratigraphic units are numbered from the oldest to youngest.

Structure

The structural/stratigraphic trend is clearly E.-W. Fold styles are isoclinal and doubly plunging. The plutonic complexes superimpose a dome and basin configuration. To the north and south the belt is bounded by "granitic" terrains. Metamorphic grade in the central area is very low; north and south of the main belt it increases rapidly.

The most pressing problem was correlation of the Archean rocks across the trough of "Hurwitz" sediments and volcanics of early Proterozoic age, which runs diagonally across the area from N.E. to S.W.

A solution was gained by expanding the zone occupied by the "Hurwitz" four to one and applying experience gained from the Superior Province. Independently of the author, Dick Bell of Brock University (pers. Comm.) arrived at an identical figure for the shortening of the crust here by analysing for strain within the "Hurwitz" itself.

The solution depicted in Fig. 4 correlates the main felsic unit, No. 4, with the main sedimentary unit, No. 4A, a relation not otherwise apparent. A similar major facies change is exhibited to the east but without the problem of Proterozoic "overburden".

A cross-section from S.W. to N.E. across the central part of the basin (Fig. 5) indicates that the structure of the area is basically a synclinorium with a central anticline cored by a massive pyroclastic-porphyry pile. The sedimentary portion of the north limb of the northern syncline appears to be cut out along a fault between the mafic volcanics of unit three and the sediments of unit four A.

The similarity of this pattern with that (Goodwin, 1965) of the Lake of the Woods (Keewatin) Belt is overwhelming. One difference from the western part of the Lake of the Woods Belt is that magnetic iron formation is abundant in the Rankin Inlet-Ennadai Belt (Davidson, 1970 a, b; Mag. maps #7297G, 7176G, 7296G). Also, the belt is clearly outlined by the geometry of its magnetic expression. To the north, the prevalent N.E. grain of the Churchill Province takes over.

Stratigraphy

In detail, the Archean stratigraphy at Kaminak Lake (Fig. 6) comprises three cycles.

The base of the oldest cycle is not yet defined satisfactorily. The oldest portion of the Archean is a sequence of basalts which forms an anticline whose axis was the lowest limit of study last summer. The minimum thickness of this pillowed and massive unit is 14,000 feet. Interlayered near the core of the anticline is a sulphide rich banded siderite and chert iron formation, perhaps as much as 100 feet true thickness. Its occurrence (Fig. 3) constitutes a stratigraphic anomaly; but there is no doubt as to its economic potential.

Abruptly overlying this oldest mafic unit lies a complex of felsic breccia and porphyry up to 6,400 feet thick. The two units together comprise the oldest volcanic cycle and are limited to the south limb of the main Kaminak synclinorium.

The succeeding cycle is the thickest and, apparently, most varied of the three. Massive and pillowed basalt (unit 3) up to 10,000 feet thick form an extensive platform on either limb of the synclinorium. Individual flows up to 500 feet thick were encountered. Relatively thin bands of interflow material characterize the sequence. Chert, black argillite, scoria, tuffs and banded carbonate all occur. The interflow material commonly carries bedded or disseminated pyrite, chalcopyrite and sphalerite; and, commonly weathers to a spectacular gossan. It is unlikely that these mineralized zones, of which marginally economic analogues exist in the Superior Province will ever be economically significant, other than for gold (e.g. Wasamac Mine, Noranda Area). Discouragement has consistently followed their investigation. However, their occurrence suggests that the second cycle is highly metalliferous and, given the appropriate environment at its uppermost levels, base metal rich massive sulphides (exhalite) will be found.

Overlying unit three, is a very large, highly differentiated felsic complex of porphyry, pyroclastics and flows (unit four). Although the chemical data is not yet available, rhyolites and their sub-volcanic equivalents appear to be abundant. Zones and bands of disseminated sulfides are present. Reasoning again by analogy (eg. Pearl Lake Porphyry, Timmins area; Upper Canada Mine, Kirkland Lake area), this felsic complex, particularly the porphyries, is probably auriferous.

Immediately overlying the rhyolitic complex is a zone of exhalite up to 30 feet thick. On the north side of the complex (Fig. 3) the exhalite is a transitional oxide/carbonate facies and is overlain by immature clastic sediments. On the south side of the complex the exhalite, which has not here been observed in outcrop, appears to be in sulfide facies and is immediately succeeded by the andesites and basalts of unit five. Coarse polymict breccia on the south limb, close to the exhalite zone, carries fragments of pyrite up to one inch in diameter. Clearly, this zone warrants greater study.

The rhyolitic complex is mantled by immature clastic sediments which may exceed 5,000 feet in thickness and are clearly derived by degradation of the

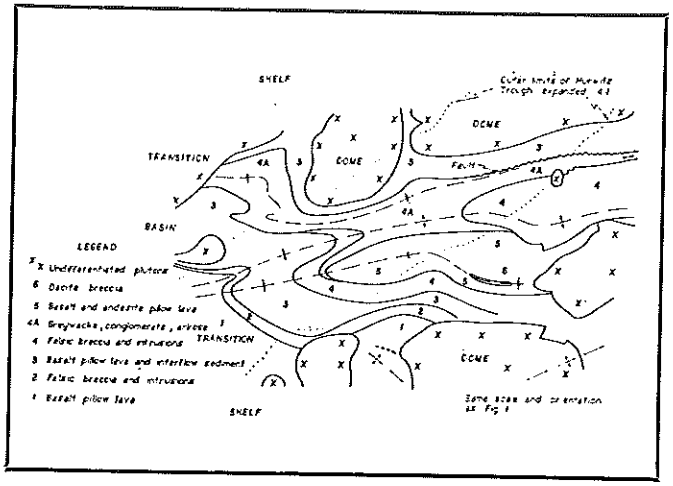


Fig. 4 Palinspastic reconstruction of the Pre-Hudsonian Geology of the North Kaminak Lake area

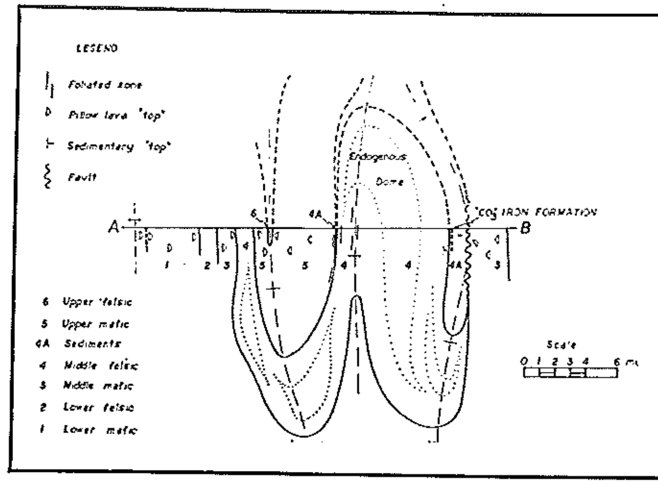


Fig. 5 Idealized cross-section of the Kaminak Synclinorium

subjacent pile. Away from the centre, grain size decreases and further to the south sedimentary iron formation is present outside the area examined.

The succeeding third cycle is incomplete in the Kaminak L. area. Unit five comprising andesite and basalt pillow and massive lava, reaches 17,000 feet in maximum thickness but its felsic descendant (unit six) is only sparingly developed in the keel of the Kaminak L. syncline (Fig. 3). Nevertheless, several thin exhalite zones were found in this youngest felsic formation. Because of its stratigraphic youth, it merits further study. It is quite possible that the main portion of this unit may be preserved elsewhere in the Belt.

By way of comparison, the overall pattern of the stratigraphy at Kirkland L. is almost identical (Ridler, 1970, p. 34). Three cycles are present. The third is incomplete. The second possesses a major period of sedimentation and includes the main zone of exhalite. Flows, breccias, interflow material and porphyries are identical. Curiously enough, an anomalous exhalite is found with basalts near the base. Two differences are, the presence of a local angular unconformity mid-way through the second cycle and the trachytic nature of the volcanism. Similar stratigraphic patterns can be demonstrated for many of the well mineralized complexes of the Superior Province.

As might be expected the map of the Kirkland L. area also displays a striking similarly to that of the Kaminak L. area (Ridler, 1969, p. 35). An E.-W. trending isoclinal synclinorium has domes impressed on it by plutonic and volcanic complexes. Oxide exhalite to the south gives way to carbonate to the north. Again, similar areal patterns exist in many of the major mining camps of the Superior Province.

Differences

What then are the differences? Three relatively minor ones, already discussed, which probably reflect incomplete data, are the utter lack of a satisfactory base to the section, the lack of any internal angular unconformities, and the somewhat thinner total maximum thickness of approximately thirty to forty thousand feet.

Hudsonian effects

The most important difference from either a theoretical or practical point of view however, is the presence of post Kenoran orogeny, in this case the Hudsonian event characteristic of the Churchill Province. As demonstrated by Fig. 3, structural effects are not pronounced within the Kaminak Lake areas. Similar relations apply elsewhere in the Rankin Inlet-Ennadai Belt. By direct observation, the metamorphic effects are not intense within the main position of the belt. Significantly, more and more Kenoran radiometric dates are turning up. However, the size of the belt may have, been "reduced" by incorporation of Archean supracrustal rocks into the wilderness of Hudsonian gneisses as discussed previously.

Nevertheless, some effects *are* present, the most notable being a penetrative cleavage parallel to the "Hurwitz" troughs. The deformation which created this fabric locally refolds the Archean axes as in the central Kaminak Lake area where the main Kaminak syncline is warped (Fig. 3). Related but more pronounced deformation on an outcrop scale may transpose original bedding surfaces. Wherever the material subjected to these forces is relatively plastic, as in the case of massive sulfides, wholesale migration into structural sites which may be highly discordant to primary bedding may occur. Colin Coates of Falconbridge has described just such a situation in the structurally and perhaps stratigraphically analgous Stall L. ore body in Manitoba (Coates et al., 1971). Truly bizarre shapes may result, but it is unlikely that these will lie remote from their original stratigraphic horizon.

Similarly, auriferous quartz veins developed late in the Kenoran orogeny may be folded or remobilized. Entirely new vein systems may develop, related to Hudsonian tectonic trends.

Metallogeny

There are two main aspects to the metallogeny of a region. First, there are those variations related by some evolutionary mechanism to time and second, those principally related to space.

In the first case, the study of the stratigraphy reveals cyclical or evolutionary changes in major lithofacies which are normally accompanied by consistent evolution of mineral deposit types. The degree of correspondence of these patterns in Archean rocks throughout the world is too great to be coincidental and hence we assume that fundamental processes of petrogenesis are directly or indirectly controlling mineral deposit genesis (Hutchinson, Ridler and Suffel, 1971). A mineral deposit is no less than a function of the stage of maturity of the fundamental petrologic evolution in an area.

In the second case, environmental variations from place to place will greatly influence the nature of coeval syngenetic mineral deposits. The most obvious example of this is exhalite facies variation (Ridler, 1970 b); or as shown in Fig. 2, sub-volcanic processes may act to concentrate metals contemporaneously with surficial deposition. Given the possibility if not probability of diachroneity, and the not uncommon habit of superimposition of lithologies and mineral deposits of differing genesis, one can readily see the advantages of any simple but realistic metallogenic model. Hopefully the one depicted in Fig. 3, the basinal volcanic complex, fulfills these requirements. Although predicated on relations observed along the south margin of the Abitibi Basin, it is generalized enough to be of much greater currency.

Variations in time

There are two basic metallogenic patterns displayed by Archean sequences in time. The first involves the overall change from simple metal deposits of Ni, Cu and gold in older cycles to more complex polymetallic Cu, Zn, Ag, Au, Fe, etc., deposits in younger cycles, in any one area. Thus the Skead/Malartic cycle (Fig. 7) possesses simple Ni, Cu and gold deposits while the younger, more complex and much more highly differentiated Blake River group is famous for its polymetallic base and precious metal rich massive sulphides, but lacks significant Ni mineralization. Similar relations appear to exist in Western Australia and South Africa. Gold is a very persistent product of volcanic processes and is found at the appropriate levels in any cycle.

The second but somewhat analogous pattern may be observed within any one cycle. Ni is associated with the mafic plate either in serpentinized ultra-mafic sills or in their extrusive equivalents. If an older felsic phase underlies a mafic plate the serpentinized sills and associated Ni mineralization may be found there. Simple Cu mineralization, often associated with interflow material also occurs. The overlying felsic pile very often contains disseminated auriferous pyrite, and rarely Cu sulfides. During the later stages of, and following the construction of the felsic domes, exhalative processes act to concentrate many elements, Fe, Au, Cu, An, Ag among the cations, and oxide, sulphate, carbonate, sulphide, arsenide and silicate among the anions, to form the various facies and subfacies of exhalite (Ridler, 1970 b). Simultaneous and subsequent degradation of the volcano apparently creates placer deposits of gold in "dirty" quartzites and conglomerates and, at greater distances from the volcano, clastic iron formation.

The application of these generally observed relations to the Rankin Inlet-Ennadai Belt as viewed at Kaminak Lake is consistent with all the limited data yet available. Ni rich serpentinites occur within basal mafic lavas as do Cu-rich interflow materials; gold occurrences are scattered, and base metal rich exhalite immediately follows the major volcanic cycle. As mentioned previously the occurrence of a thick exhalite low in the sequence is an intriguing enigma.

Variation in space

Many of the economically interesting metallogenic variations in space can be satisfactorily understood within the context of basin analysis and the facies concept. Put simply, iron formation may be considered as one of two major types, either a clastic or chemical sediment. The former is associated with immature clastic sediments at some distance from their volcanic or proto-continental provenance. It is characteristically low in base and precious metals but may constitute iron ore. The latter, or "exhalites" are a happy blend of prime economic and theoretical interest.

Exhalites vary in anion composition regionally to form zones concentric to the original basin. We assume that a variation across sedimentary strike on a regional basis from oxide to carbonate to sulphide corresponds to an increase in water depth. Wherever a volcanic complex is within the sulphide or sulphidic carbonate facies and exhaling base or precious metals, significant mineralization may occur. Base metals occur near the volcano, often directly over an exhalative pipe, whereas gold is more widely dispersed. With increasing distance from a volcanic centre, the chances of exhalite occupying an unrelated or marginally related lithofacies increases and indeed individual exhalite zones not uncommonly cross from volcanic to sedimentary environments (Fig. 6). At this point dilution by foreign materials may effectively mask the exhalite interval for significant distances; however, exhalite is habitually geographically persistent and it is not uncommon for an entire basin to be ringed by a major zone (Goodwin and Ridler, 1971). In fact, it is axiomatic that exhalite is a characteristic Archean rock type.

It is important to note that the exhalite process wherever operating efficiently will concentrate economically attractive metals regardless of paucity in associated rocks. It follows that regional rock geochemistry may be very misleading as to the economic potential of a belt. Far better to examine the trace element geochemistry of the regional exhalite which by itself indicates that the appropriate process was operative. Since the oxide facies of the regional exhalite zone can usually be located from magnetic maps and facies commonly overlap; a powerful exploration method of great resolving power is suggested.

At Kaminak Lake (Fig. 4) the regional distribution of exhalite facies is not fully documented yet, but appears to show an outside to central transition from oxide to carbonate/sulphide facies, the normal case. At least the central portion could well be entirely in sulphide facies. Thicknesses in excess of 50 feet are present and base metal rich subfacies have been explored (Wright, 1967, p. 80). The common occurrence of Cu and Zn in interflow material is consistent with their occurrence in the main sulphide facies. Much are effort will be directed towards tracing out the exhalite next summer.

Conclusions

The Archean rocks of the Rankin Inlet-Ennadai Belt are similar in most geological respects to the well known "greenstone" belts of the Superior Province. In the Kaminak L. area a complex volcanic centre of great thickness comprises three sequential mafic to felsic cycles. Felsic volcanics are abundant and well differentiated including rhyolite and quartz porphyry. Significant exhalative and clastic sedimentation accompanied and followed the second cycle. Curosry examination of the exhalite revealed regional zones of oxide, carbonate and sulphide facies.

Post Kenoran orogenic effects are real but surprisingly light throughout much of the belt. Remobilization of some sulphide and gold-quartz vein mineralization into Hudsonian structural sites may have occurred.

The co-incidence of so many favorable stratigraphic, structural and metallogenic factors in the Rankin Inlet-Ennadai Belt inescapably leads to the conclusion that major ore deposits of Ni, Cu-Zn, Au-Ag and Fe, analogous to those in the Superior Province will reward the diligent application of modern geological, geophysical and geochemical techniques.

References

Coats, C. J. A., Clark, L. A., Buchan, R. and Brummer, J. J., 1971, Geology of the Copper — Zinc Deposits of Stall Lake Mines Ltd., Snow Lake Area, N. Manitoba; Econ. Geol. v. 65, 10. 8, pp. 970-984.

Davidson, A., 1970 a, Precambrian Geology, Kaminak Lake Map — Area, District of Keewatin; G.S.C. Paper 69-51, 27 p.

——————, 1970 b, Eskima Point and Dawson Inlet Map — Areas (North Halves) District of Keewatin 55 E and 55 F (north parts); G.S.C. Paper #70-27, 21 p.

Goodwin, A. M., 1965, Preliminary Report on Volcanism and Mineralization in the Lake of the Woods — Manitou Lake — Wabigoon Region of Northwestern Ontario; O.D.M. P.R. 1965-2, 63 p.

Goodwin, A. M. and Ridler, R. H., 1970, The Abitibi Orogenic Belt, in Symposium on Basins and Geosynclines of the Canadian Shield, G.S.C. Paper. 70-40, pp. 1-24.

Hutchinson, R. W., Ridler, R. H. and Suffel, G. G., 1971, Metallogenic Relationships in the Abitibi Belt, Canada. A Model for Archean Metallogeny; C.I.M. Bull., v. 64, no.. 708, pp.

Ridler, R. M., 1970 a, Relationship of Mineralization to Volcanic Stratigraphy in the Kirkland — Larder Lakes Area, Ontario; Proceedings of the G.A.C., v. 21, pp. 33-42.

——————, 1970 b, Metallogeny and Iron Formation, Kirkland Lake — Noranda — Cadillac; G.A.C. Programme and Abstracts Ann Meeting, 1970, pp. 44.

——————, 1971, Volcanic Stratigraphy and Metallogeny of the Kaminak Group; G.S.C. Paper 71-1, Part A, pp. 142-148.

Wright, G. M., 1967, Geology of the southeastern barren grounds; parts of the Districts of Mackenzie and Keewatin; G.S.C. Mem. 350, 91 p.