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JHC

ASARCO

Southwestern Exploration Division

November 24, 1980

MEMO FOR: D. M. Smith

FROM: J. H. Courtright

WIND RIVER FM. - GOLD
Wyoming
(Research)

The attached xerox copy from Geological Survey Research 1978 states that "substantial quantities of gold occurs in the roundstone conglomerates which continue eastward with no diminution in grade."

You may already be familiar with this occurrence; if not, perhaps it could be determined whether or not "substantial quantities" amounts to anything approaching ore grade.

J. H. Courtright
J. H. Courtright

JHC:jlh
encls
c.c. RLBrown
WLKurtz

### Faulting in the Duluth Complex in Minnesota

Preliminary results of large-scale (1:24,000) mapping in the Duluth Complex in Minnesota by M. P. Foose and R. W. Cooper for the first time gives evidence for the presence of a large number of faults. Most of the faults appears to have only small (<100 m) normal or strike-slip displacements, but some faults, mostly with northeast-southwest trends, represent major discontinuities of undetermined size. The intense fracturing is similar in style to tensional regimes such as the Basin and Range and suggests a paleorift origin for the Duluth Complex. The recognition of faulting is important in evaluating the continuity of nickle–copper ores in the complex and in estimating the region's nickle–copper resources.

### Potential economic significance of gahnite (zinc spinel) in Colorado

During recent field investigations in Colorado, D. M. Sheridan and W. H. Raymond found that gahnite, a zinc spinel, occurs in and near many Precambrian sulfide deposits in the Front Range, Park Range, Wet Mountains, and Salida regions. Although sphalerite, chalcopyrite, and lesser amounts of silver-bearing galena are the principal sulfide ore minerals in these deposits, a newly recognized concept identifies potential economic significance of gahnite (Sheridan and Raymond, 1977). Gahnite may be sufficiently abundant at some of the deposits to constitute an ore mineral. Samples of gahnite-rich rocks from various mines and prospects range in zinc content from 3.5 to 19 percent, and the pure mineral contains up to 27 percent Zn. Moreover, the geologic relations found in some localities suggest that gahnite may be used as a significant guide for prospecting, characterizing favorable lithologic trends, even where cogenetic sulfides are sparse or absent in outcrops.

### Production of quartz-muscovite schist from Poncha Pass area in Colorado

A wide extensive zone of Precambrian quartz-muscovite schist is being mined in the Bonanza northeast quadrangle northwest of Poncha Pass, Colo. The schist is excavated from open cuts, transported to nearby Salida for crushing and screening, and then shipped by rail to Denver for use in making bottles; previously it was used in gypsum board, paint, and insulation material. R. E. Van Alstine reports that the steep schist zone locally is more than 150 m thick and extends north from Highway U.S. 285 for about 1.6 km. It is localized along one of the faults that bound the east side of the north extension of the Rio Grande trough. In 1975 and 1976 schist produced from here was valued at $100,000 each year (Colo. Div. Mines, 1976, p. 21, 23, 74, and 109; Colo. Div. Mines, 1977, p. 11, 53).

### Course of Eocene Wind River locates auriferous sedimentary rocks in the western Wind River Basin in Wyoming

The distribution of roundstone conglomerates in the upper part of the Wind River Formation in the western part of the Wind River Basin was found by D. A. Seeland to coincide exactly with the course of the Eocene Wind River as determined by a study of crossbedding in the sandstones of the Wind River Formation. This is most significant because analysis of panned concentrates from these roundstone conglomerates indicates the presence of a substantial quantity of gold. The volume of conglomerate decreases eastward, but there is no eastward diminution of grade. Thus, if sandstones of this stratigraphic horizon exist to the east and contain similar gold values, then the course of the Eocene Wind River should define the location of a substantial additional volume of auriferous rocks.

### Carbonatite dikes in Bear Lodge Mountains, Wyoming

Numerous carbonatite dikes were recognized by M. H. Staatz in cores from deep drilling of alkalic rocks in the southern Bear Lodge Mountains. These intrusive rocks, which dome up the surrounding sedimentary rocks, are principally trachyte and phonolite. At depth they tend to be coarser grained and become fine-grained syenite and nepheline syenite. As many as 22 carbonatite dikes have been encountered in one hole. One carbonatite was subsequently found on the surface during detailed mapping. The dikes range in thickness from about 1 mm to 5 m. Calcite is the principal mineral. Other minerals commonly found in many samples are bastnaesite, ancylite, strontianite, pyrite, pyrrhotite, sphalerite, and galena. In addition at least 14 other minerals have been identified in various samples. These carbonatites, like the massive carbonatite at Kangankunde Hill, Malawi, are both rare-earth and strontium-rich. Samples of the Bear Lodge carbonatites containing 2 to 5 percent rare-earths and 3 to 10 percent strontium are common.

### Relationships of copper and gold deposits in the ophiolitic Canyon Mountain Complex in Grant County, Oregon

Until recently, copper and gold veins in the Canyon Mountain Complex in Oregon had been as-

JHC

ASARCO

Exploration Department

December 1, 1980

FILE MEMO

PORPHYRY COPPER RESEARCH

Xerox copies of two items of interest (Geological Survey Research 1978) are attached.

(1) The Shultz "Granite" of the Globe-Miami District consists of a three-phase quartz monzonite intrusive. All disseminated sulphide mineralization is in, or adjacent to, the youngest phase ----- the most conspicuously porphyritic. A close relation between the development of porphyry textures and the introduction of copper-iron sulphides is implied ----- "whatever the nature of the ore-forming process."

(2) Results of laboratory work on rocks from the Ray District conflict with both the ortho-magmatic and meteoric water models of porphyry copper genesis. A new model is proposed, which ".....explains the failure to discover petrologic and chemical distinctions between 'ore' and 'non-ore' plutons." Regional structure is given renewed emphasis in exploration.

J. H. Courtright

J. H. Courtright

JHC:jlh
attmt
c.c. RLBrown
WLKurtz
DMSmith
JCBalla
REGale
RSGray

rocks; and the data are best explained if the copper and most of the sulfur, chlorine, and water in the magmas were used by the igneous minerals during crystallization of the magmas. The stocks, and by analogy any parental upper crustal magma, thus were themselves unlikely to produce an ore fluid. Furthermore, not only did the stocks contain little copper and sulfur to supply to an ore fluid of circulating meteoric water, but also copper was more likely added to rather than extracted from the rocks in the outer parts of a circulation cell. Incorporated into the new model is the petrologic confirmation that sulfur is essentially insoluble in siliceous silicate melts, and it is postulated that sulfide minerals accumulate in a zone of partial melting around, but not in, pockets of magma. Some of the magma is mobilized and intruded into the upper crust. The sulfides, however, remain in the zone of partial melting until local or regional cessation of melting allows excess metamorphic and late magmatic water to be present, which remobilizes and transports the sulfides to upper crustal sites. The new model explains the time-space relationship of ore and magma. It also explains the failure of considerable research to discover petrologic and chemical distinctions between "ore" and "non-ore" plutons. The model places renewed emphasis on regional structure in delineating favorable zones and localities for discovery of ore.

#### Geology of the Cuprite mining district of Esmeralda County in Nevada

Studies by R. P. Ashley show that the Cuprite mining district contains mineralization of two different types and ages. The younger is characterized by intense acid-sulfate alteration that has converted Cambrian siltstones and Tertiary tuffs, flows, and volcanic sedimentary rocks to silicified, opalized, and argillized rocks. Mineral production associated with this alteration includes only minor amounts of sulfur, silica, and clay. Potential for substantial discoveries of commercial sulfur and clay is low, for silica the potential is high, and for gold and mercury it is low to moderate. Alunitic rock exists, but its tonnage is too small and its mineralogy too unfavorable for exploitation by presently contemplated commercial processes.

The older mineralization at Cuprite consists of base-metal veins (mainly copper-lead) with minor precious metal values (mainly silver) in unaltered to locally hornfelsic Cambrian siltstones. This mineralization is probably Mesozoic in age, associated with a buried pluton. These veins have little economic potential, but minor potential exists for disseminated copper mineralization at depth.

#### Molybdenum mineralization in the Battle Mountain mining district of Lander County, Nevada

Numerous base and precious metal deposits in the Battle Mountain mining district are related to Upper Cretaceous and middle Tertiary granodiorites to quartz monzonites emplaced into thick sequences of Paleozoic sedimentary rocks. Molybdenum mineralization occurs sporadically throughout the district, but is especially concentrated in an elongate stockwork system near Copper Basin that is being studied jointly by T. G. Theodore and J. N. Batchelder (USGS) and D. W. Blake and E. L. Kretschmer (Duval Corporation). This system is related to numerous small Tertiary(?) quartz monzonite intrusions. Near Copper Basin the emplacement of most intrusive rocks was controlled by two prominent fracture sets, one striking N. 70° W. and the other north-south. The molybdenite mineralization, including very minor chalcopyrite, is related mostly to the N. 70° W. set. In addition, other mineralized fractures striking approximately N. 45° W. and N. 45° E. acted as important conduits for mineralizing fluids. Many of the molybdenite-stockwork veins and their selvages reflect locally intense potassic alteration, and the veins typically contain potassium feldspar-biotite-calcite-molybdenite, and quartz-molybdenite-calcite ± potassium feldspar ± white mica assemblages. The molybdenite-bearing veins contain abundant liquid plus vapor fluid inclusions. Preliminary fluid-inclusion studies of these veins suggest the bulk of the molybdenite mineralization occurred during circulation of nonboiling to slightly boiling, moderately saline fluids that range mostly between 8 and 12 weight percent NaCl equivalent. Temperatures were approximately 300° to 400°C. The values of $\delta^{18}O$ of the water calculated to be in equilibrium with hydrothermal quartz from molybdenite-bearing veins are +5.7 to +6.2, an unusually restricted range suggesting significant isotopic exchange with the wallrocks. Last, the molybdenite-stockwork system has been intruded extensively by a series of late north-south-striking, westward-dipping quartz latite porphyry dikes associated with minor lead and zinc mineralization.

#### West-northwesterly structural zone controlled gold mineralization at Manhattan in Nevada

Geologic mapping by D. R. Shawe in the vicinity of Manhattan shows a major west-northwest-trending zone of faults that was probably a primary con-

ASARCO

Southwestern Exploration Division

April 28, 1978

J. H. C.

MAY 1 - 1978

TO: S. Von Fay

FROM: F. T. Graybeal

"Wrigglite", or swirly layered structure

The papers on wrigglite from Mr. Williamson forwarded by you bring to mind two additional occurrences of a similar texture. One is in the Christmas mine in Arizona briefly discussed by Perry (Econ. Geol., 1969, p. 261-262) as a swirly layered structure accentuated by thin magnetite bands. The rock is a thinly layered serpentine-talc-garnet-olivine-sulfide-magnetite skarn which occurs as an epigenetic replacement of the fetid dolomite unit of the Martin Formation. Although this rock does not to my knowledge host the F-Be-Sn-W assemblage, specimens of it I have seen are identical to the pictures attached to Mr. Williamson's report.

The second occurrence at Mt. Haskin, British Columbia, located about 15 miles east of Cassiar, is a swirly layered magnetite skarn exposed in a trench and in core from several drill holes. Although petrographic work is not available, the rock occurs as a replacement of Paleozoic limestone adjacent to the contact of a granite porphyry stock. Drilling along this contact by Della Mines Ltd. (one of Andy Robertson's companies) established a reserve of roughly 20 million tons of 0.12-0.15% $MoS_2$ in a chert along with discontinuous zones of Pb-Zn-Cu-Ag in the skarn. Small amounts of fluorite were mapped along this contact and, as of 1969, no analyses had been made for Sn-W-Be. This area is a few miles northwest of Reed Mtn. which I understand is now being reviewed by the Vancouver Office.

F. T. Graybeal

F. T. Graybeal

FTG:lb

cc: TCOsborne
JHCourtright
WLKurtz
REGale

New York, March 15, 1982

MEMORANDUM FOR: Messrs. W. L. Kurtz
J. C. Balla
E. P. Bayley
R. E. Gale
D. D. Harper
W. D. Payne
E. W. Perkins
D. M. Smith, Jr.
J. H. Courtright
P. G. Vikre
A. Giesecke

Rare Earth Elements in
Volcanogenic Environments

The attached paper which was provided by Mr. Gray proposes a technique which may permit recognition of productive volcanogenic environments from barren environments. This paper should be of some interest to you and your staff regardless of your involvement (or lack of it) in these environments. The interest in rare earth geochemistry has been increasing over the past decade but to my knowledge this represents the first real application to a subject of interest to explorationists. I suspect there will be forthcoming attempts to apply the concepts described to other types of deposits. The paper is recommended reading and please circulate it to all members of your staff.

F. T. Graybeal

F. T. Graybeal

Enclosure

cc: RLGray wo/encl.
HCWilliamson wo/encl.

Ontario Geological Survey
Miscellaneous Paper 98

# Geoscience Research Grant Program

## Summary of Research 1980-1981

edited by
E.G. Pye

1981

Ontario

Ministry of Natural Resources

Hon. Alan W. Pope
Minister

W. T. Foster
Deputy Minister

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# Grant 80 Rare Earth Elements in Felsic Volcanic Rocks Associated with Cu-Zn Massive Sulphide Mineralization

I.H. Campbell[1], P. Coad[2], J.M. Franklin[3], M.P. Gorton[1], T.R. Hart[1], S.D. Scott[1], J. Sowa[1] and P.C. Thurston[4]

[1]Department of Geology, University of Toronto
[2]Texasgulf Canada Ltd.
[3]Economic Geology Division, Geological Survey of Canada
[4]Ontario Geological Survey

## ABSTRACT

Massive sulphide deposits are closely associated with felsic volcanism. This association is believed to be genetic and forms the cornerstone for most exploration programs, but unfortunately not all felsic volcanic rocks contain ore. It seems likely that ore-bearing felsic volcanic rocks have a different genetic history from barren felsic volcanic rocks and, if this is so, these differences should be reflected in their rare earth element (REE) geochemistry.

A preliminary study of REE in Archean felsic volcanic rocks has shown that those associated with ore have flat REE patterns with well developed Eu anomalies whereas those from barren volcanic rocks have steep REE patterns with weak or absent Eu anomalies. The felsic volcanic rocks associated with ore can be sudivided into two types: tholeiitic and calc-alkaline. Those at the Kam-Kotia, Matagami and South Bay mines are tholeiitic whereas those at the Sturgeon Lake and Golden Grove deposits are calc-alkaline.

The well-developed Eu anomalies in the ore-related felsic volcanic rocks indicate that the melt has undergone a high degree of fractional crystallization en route to the surface, suggesting the existence of a subvolcanic magma chamber below the ore body. We believe that these subvolcanic sills are an integral part of the ore-forming process and are therefore required for the formation of massive sulphide deposits.

The characteristic REE patterns of the ore-associated felsic volcanic rocks should help mining companies in selection of areas for massive sulphide exploration.

## INTRODUCTION

An important characteristic of Archean Cu-Zn massive sulphide deposits is their close association with felsic volcanic rocks. This association is believed to be genetic and forms the cornerstone for most exploration programmes. The presence of felsic volcanic rocks on an exploration property does not guarantee success, however, as most are barren. If some way can be found to distinguish between barren and ore-bearing felsic volcanic rocks, or if certain types can be eliminated as potential target areas, exploration companies will be able to direct their efforts where they are most likely to succeed.

Where Cu-Zn deposits are found in areas of cyclic volcanism, they occur in specific units. For example, at Sturgeon Lake they are found at the top of cycles 1a and 1b (Franklin 1978) and at Uchi Lake in the uppermost of three felsic horizons (Thurston, in press). The implication is that certain felsic volcanic rocks, by virtue of their genetic history, are associated with massive Cu-Zn mineralization. Although the genetic significance of REE patterns is not always clear, we can be confident that they are governed by fundamental partial melting and fractionation processes (Gast 1968; Shaw 1970). There should therefore be a distinct difference between the REE geochemistry of barren and ore-bearing rocks.

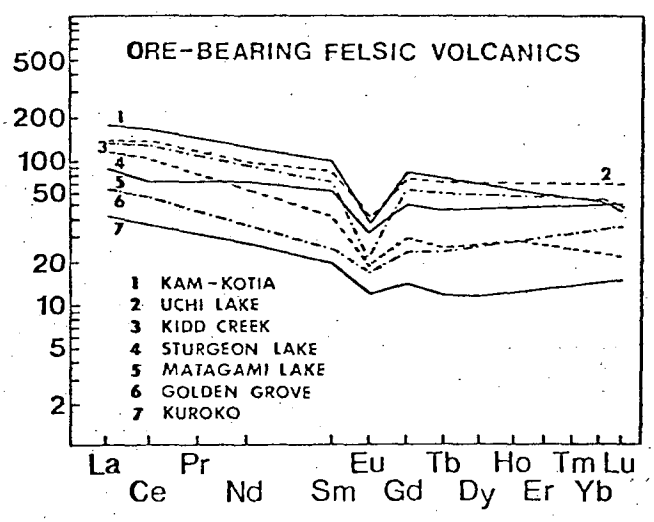


*Figure 1—Chondrite-normalized REE patterns for seven ore-bearing felsic volcanic units. Data for Matagami Lake unit from MacGeehan and MacLean (1980).*

To test this hypothesis we have commenced a study of the trace element geochemistry of ore-bearing felsic volcanic rocks, paying special attention to immobile trace elements such as Y, Ti, Zr and the REE. In this report we present preliminary data from four ore-bearing units. The results are encouraging and should be of interest to mining companies.

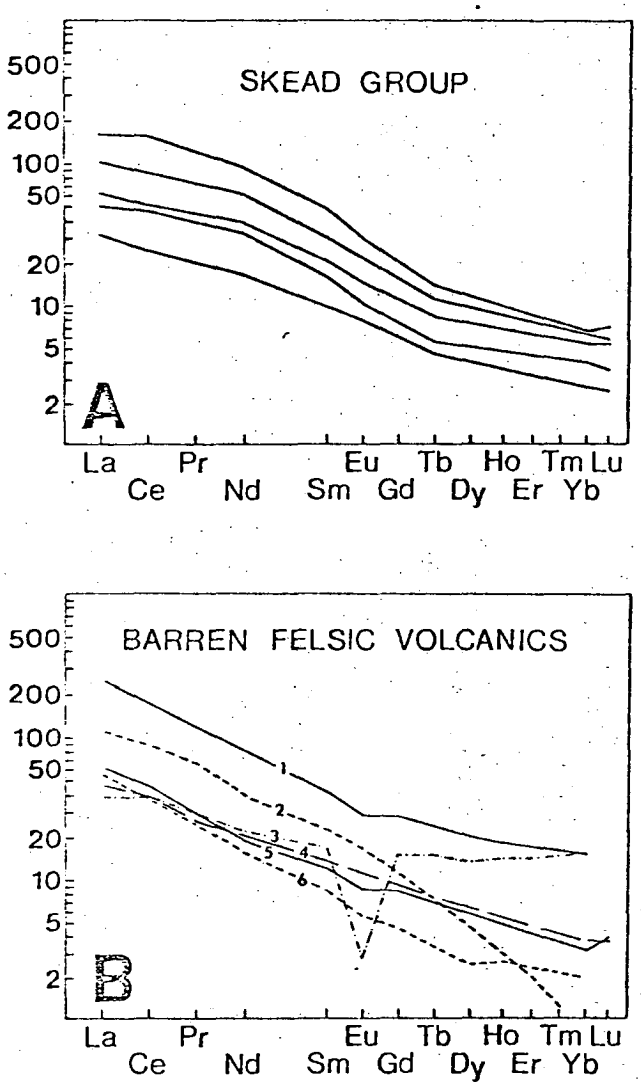


*Figure 2—A. Chondrite-normalized REE patterns for six barren felsic volcanic units from the Skead area, Abitibi "greenstone" belt. (From unpublished data, Goodwin and Gorton). B. REE patterns for six barren felsic volcanic units. 1 = Marda dacite (Taylor and Hallberg 1977), 2 = Middle Marker porphyry (Glikson 1976), 3 = Marda rhyolite (Taylor and Hallberg 1977), 4 = Rhyolite, cycle 4, Sturgeon Lake, 5 = Hanging wall quartz-eye ash flow, Golden Grove, 6 = Onverwacht porphyry (Glikson 1976).*

Prior to the commencement of this study Thurston (in press) demonstrated that the REE patterns of samples from the ore-bearing horizon of the South Bay Mine were distinctly and consistently different from those of the other horizons. He found that the patterns from ore-bearing horizons were only slightly enriched in light rare earth elements (LREE) and had a pronounced Eu anomaly whereas those from barren felsic volcanic rocks showed strong LREE enrichment and Eu anomalies were weak or absent. Thurston has also presented REE patterns of a reconnaissance nature for ore-bearing volcanic rocks from the Kam-Kotia area near Timmins, Ontario. These patterns appear to be similar to those of the South Bay ore-bearing rhyolite.

# RESULTS

The data from our study, together with one pattern obtained from the literature, are presented in Figure 1. The patterns from the ore-bearing felsic volcanic rocks are characteristically flat (low La/Lu ratios) and have well developed Eu anomalies. REE patterns for barren felsic volcanic rocks from the Abitibi "greenstone" belt are presented in Figure 2a and for other "greenstone" belts in Figure 2b. With one exception, they show strong LREE enrichment and Eu anomalies are weak or absent. The exception is a rhyolite from the Marda area in Western Australia. It has a flat REE pattern similar to those in Figure 1 and a well developed Eu anomaly. Significantly, several showings of Cu-Zn mineralization have been found in the Marda area, but none has been shown to be economic.

## EFFECTS OF ALTERATION

The volcanic rocks which host massive Cu-Zn sulphide deposits are invariably altered. MacGeehan and MacLean (1980) have suggested that the alteration associated with massive sulphide deposits can result in mobilization of so-called "immobile" trace elements such as Y, Zr, Ti and REE. Before REE can be used as a guide to area selection in massive sulphide exploration, some assessment must be made of their mobility. We have begun such a study in the Sturgeon Lake area. Here Franklin *et al.* (1975) recognised two types of alteration: pervasive, low intensity alteration extending up to 4 km from the ore deposits, and more localized high-intensity alteration which forms the alteration pipes below the ore bodies. We have collected samples from both alteration zones and from the unaltered rhyolite. REE patterns from the low intensity alteration zone, which is characterized by alkali depletion, are identical to those from unaltered samples. Samples from the mine rhyolite, collected from the alteration pipe below the ore body, have variable REE patterns and do show evidence of REE mobility. They have a lower REE content than unaltered rhyolites and most samples show evidence of heavy rare earth element (HREE) enrichment (Figure 3d). Chloritized samples from Golden Grove and Kidd Creek also show HREE enrichment.

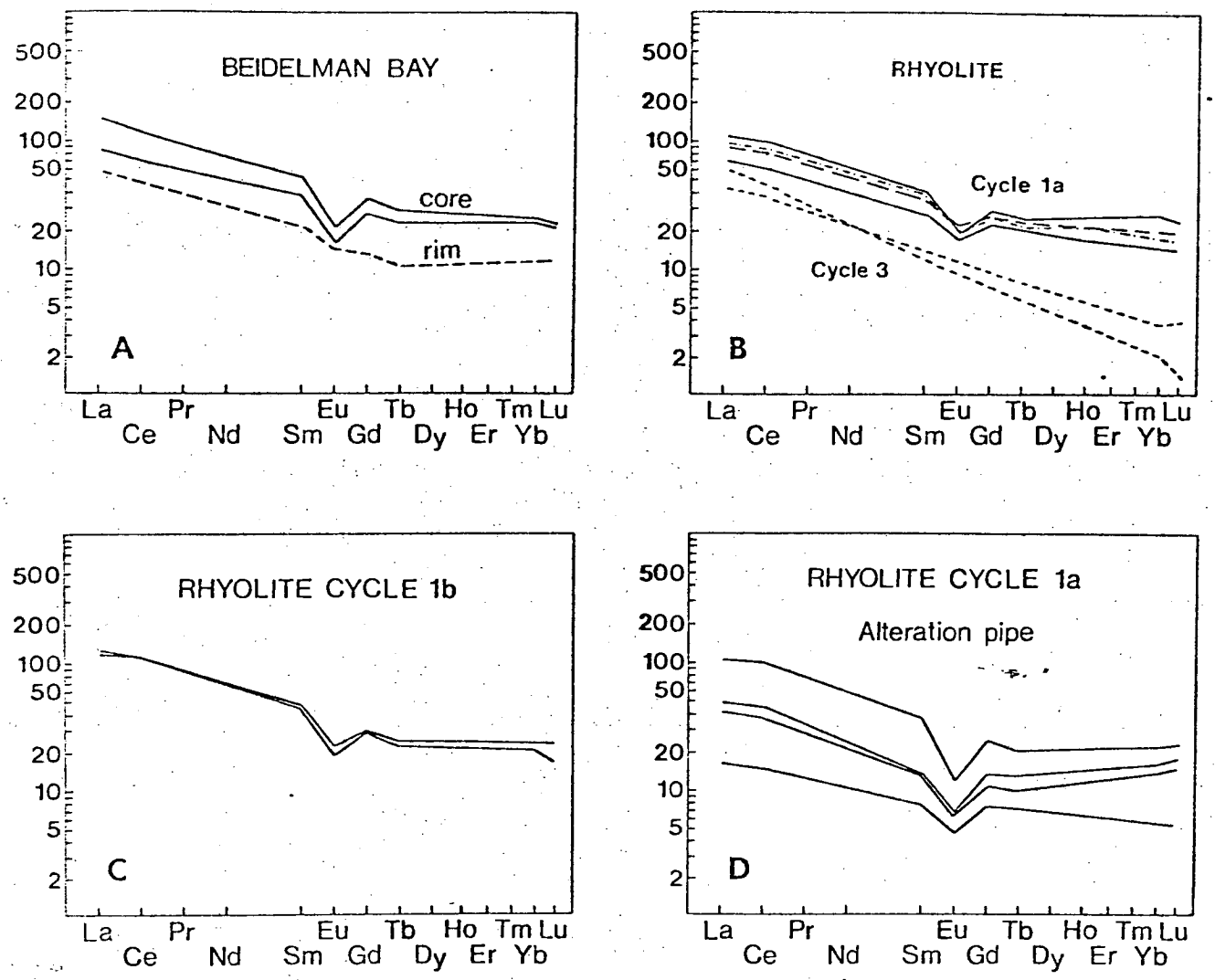


*Figure 3—Chondrite-normalized REE patterns for rhyolites from Sturgeon Lake.* ***A.*** *Beidelman Bay Complex;* ***B.*** *volcanic cycles 1a and 3;* ***C.*** *volcanic cycle 1b;* ***D.*** *samples from the alteration pipe below the Mattabi Mine.*

## SUBVOLCANIC MAGMA CHAMBERS

The flat REE patterns of ore-bearing horizons with their characteristic Eu anomalies indicate that the parent magmas have undergone extensive fractional crystallization, implying the existence of magma chambers beneath the ore deposits. This hypothesis is in agreement with current theories for the origin of the Kuroko massive sulphides. These deposits, like Archean massive sulphides, are typically accompanied by extensive alteration zones. Calculations by Cathles (1978) and Urabe and Sato (1978) indicate that the heat released by the rhyolite dome during volcanism can produce only a small fraction of the heat necessary to drive the required hydrothermal system. They predict the existence beneath the ore deposits of a shallow-level magma chamber which they argue would act as a heat engine.

Archean massive sulphide deposits, unlike the Kuroko deposits, are turned on their side, exposing their "plumbing" for inspection and sampling. Significantly, most Archean massive sulphide deposits have subvolcanic sills (high-level magma chambers) in their footwalls. Examples are found at Uchi Lake, Snow Lake, Sturgeon Lake, Noranda, Kam-Kotia and Matagami. Two examples are illustrated in Figures 4 and 5.

We have tested this hypothesis by comparing the trace and major element abundances of the ore-bearing felsic volcanic rocks with those of the subvolcanic magma chamber. Typical results from Sturgeon Lake and Kam-Kotia are given in Figures 3 and 6 (REE) and in Tables 1 and 2 (major elements). It is clear from these results that these subvolcanic sills were the magma chambers which fed the overlying volcanic sequence. We

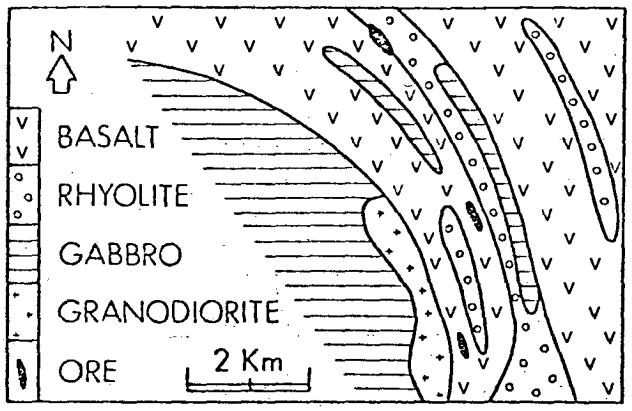


*Figure 4—Simplified plan of the Kam-Kotia area showing the relationship between the volcanic rocks and the subvolcanic magma chamber. Dips in the area are steep and stratigraphic tops face northeast.*

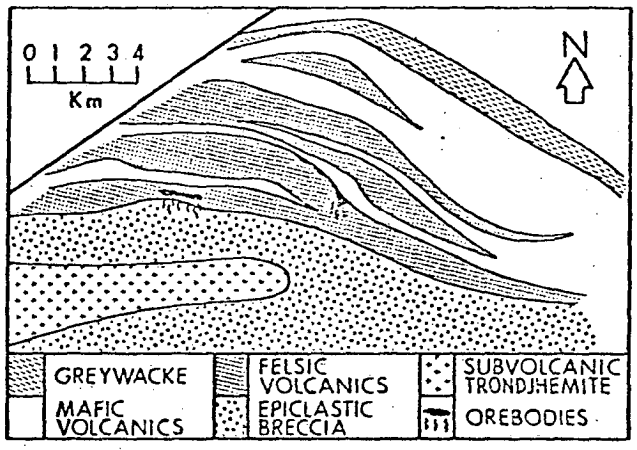


*Figure 5—Simplified plan of the Sturgeon Lake area showing the relationship between the Beidelman Bay Complex (subvolcanic trondhjemite) and the ore deposits. Dips in the area are steep and stratigraphic tops face north.*

believe this link is important and that the subvolcanic sills form an essential part of the ore-forming system.

# RESULTS FOR INDIVIDUAL AREAS

## 1. STURGEON LAKE AREA

The geology of the Sturgeon Lake area is described by Franklin *et al.* (1975; Franklin 1978). Three cycles of volcanism are recognized, a typical cycle having basaltic andesite at its base and felsic pyroclastic rocks at the top. The ore deposits are found at the top of cycles 1a and 1b (see Figure 5). The base of the sequence is intruded by a subvolcanic sill, the Beidelman Bay Complex, which geochemical evidence suggests is the magma chamber which fed cycles 1a, 1b and 2. The barren felsic volcanic rocks of cycle 3, however, had a different source. Their REE patterns are steeper than those of the Beidelman Bay Complex and they have no Eu anomalies (Figure 3b).

Franklin (1978) has divided the Beidelman Bay Complex into two zones: an outer quartz diorite margin or rim and an inner trondhjemitic core. The outer dioritic margin has a calc-alkaline REE pattern, no Eu anomaly and an $SiO_2$ content of 65 percent, whereas the inner core has $SiO_2$ contents in the range of 74-78 percent, higher REE contents and strong Eu anomalies (Figure 3a). The inner liquid has clearly developed from fractional crystallization of a parent liquid represented by the outer dioritic margin. This has two effects on the REE pattern, firstly it raises the level of REE in the melt, producing a pattern parallel to that in the original melt but at a higher level and, secondly, it results in the development of a Eu anomaly. Fractional crystallization cannot be the result of crystal settling as the rate of separation of crystals from melt in a viscous felsic magma is too slow to produce efficient fractionation. It is more likely that the intrusion has crystallized from the outside in, the liquid being separated from the growing crystals by a combination of diffusion and convection. Most petrologists studying layered intrusions now accept that fractional crystallization results from in situ growth of the cumulus minerals at the sides and floor of the magma chamber (Campbell 1973, 1978; McBirney and Noyes 1979; Irvine 1980) and this would seem the most viable mechanism to explain fractional crystallization in granitoid magmas.

## 2. KAM-KOTIA AREA

The massive sulphides of the Kam-Kotia area are associ-

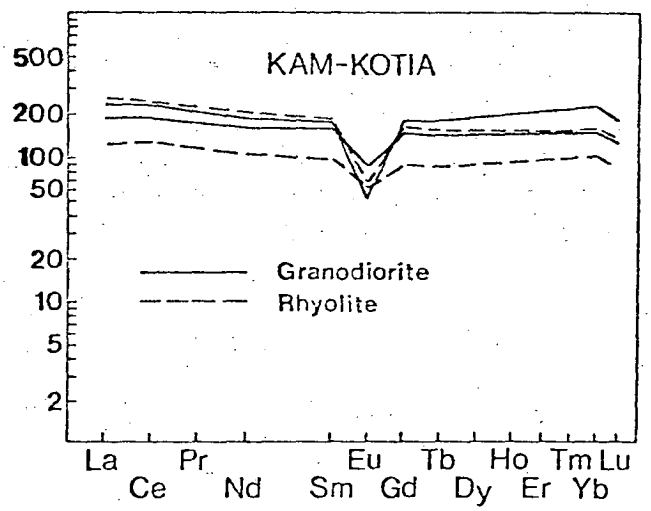


*Figure 6—REE patterns for the Kam-Kotia subvolcanic magma chamber and the ore-associated rhyolites.*

*Table 1—Major element abundances in rocks from Kam-Kotia Mine area.*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.77 | 47.20 | 51.73 | 50.94 | 73.17 | 71.20 | 72.32 | 73.12 | 77.58 |
| $TiO_2$ | 1.07 | 0.76 | 1.37 | 1.13 | 0.32 | 0.35 | 0.53 | 0.28 | 0.27 |
| $Al_2O_3$ | 14.40 | 15.05 | 13.67 | 12.40 | 10.71 | 10.36 | 11.77 | 11.62 | 11.15 |
| FeO* | 10.93 | 9.14 | 12.95 | 13.37 | 4.50 | 5.10 | 5.59 | 3.45 | 1.41 |
| MnO | 0.19 | 0.10 | 0.23 | 0.38 | 0.02 | 0.08 | 0.11 | 0.01 | 0.01 |
| MgO | 6.43 | 8.25 | 5.87 | 7.70 | 0.04 | 0.45 | 0.22 | 0.99 | 0.18 |
| CaO | 10.17 | 8.45 | 7.79 | 3.73 | 1.33 | 1.55 | 4.17 | 0.47 | 0.16 |
| $Na_2O$ | 1.53 | 2.76 | 3.89 | 1.31 | 5.51 | 5.21 | 0.63 | 2.50 | 0.67 |
| $K_2O$ | 0.63 | 0.22 | 0.50 | 0.26 | 0.89 | 1.57 | 2.15 | 4.89 | 8.16 |
| $P_2O_5$ | 0.20 | 0.03 | 0.11 | 0.14 | 0.03 | 0.03 | 0.10 | 0.04 | 0.03 |
| Loss | 2.75 | 6.77 | 2.86 | 7.01 | 3.58 | 4.62 | 2.19 | 2.89 | 0.95 |
| TOTAL | 98.07 | 98.73 | 100.97 | 98.37 | 100.10 | 100.52 | 99.78 | 100.26 | 100.57 |

Sample Description: No. 1-2 gabbro, 2-3 basalt, 5-6 granodiorite, 7-9 rhyolite.

*Total Fe as FeO

ated with a bimodal sequence of rhyolite and tholeiitic basalt. This sequence is underlain by a large layered tholeiitic sill which has fractionated with a strong Fe-enrichment trend (Middleton 1974). At the top of the sill is a layer of granodiorite which is geochemically similar to the overlying felsic volcanic rocks (Figure 6). Although the granodiorite is clearly related to the underlying gabbro it is unlikely to be the product of simple fractional crystallization since Fe-enrichment in a tholeiite is typically accompanied by $SiO_2$ depletion (Wager and Brown 1968). One possible explanation for the granodiorite is that it separated as an immiscible liquid during the final stages of fractionation of the sill. Immiscible liquids are a common feature in Fe-rich tholeiites (McBirney and Nakamura 1974; Gélinas *et al.* 1976) and it is possible that, during the final stages of crystallization, the magma may have split into two immiscible fractions; a felsic liquid and an Fe-rich tholeiite. Studies of the partitioning of REE between immiscible felsic and mafic melts have shown that the REE preferentially enter the mafic liquid but that the La/Lu ratio in the two liquids is the same (Hess 1980). La/Lu ratios in the granodiorite are similar to those in the felsic volcanic rocks and the underlying gabbros, but we have not yet found Fe-rich tholeiites with a REE content greater than that of the granodiorite.

An alternative explanation is that the granodiorite represents the $SiO_2$-rich top of the type of zoned magma chamber envisaged by Hildreth (1979). We suggest that the felsic volcanic rocks of the Kam-Kotia area are the eruptive equivalent of the granodiorite and that both derive their flat REE patterns from their tholeiitic parent.

*Table 2—Major element abundances in rocks from Sturgeon Lake area.*

| Sample No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 61.47 | 73.88 | 73.95 | 73.60 | 74.30 | 73.62 | 70.16 | 77.36 |
| $TiO_2$ | 0.75 | 0.51 | 0.30 | 0.68 | 0.39 | 0.50 | 0.35 | 0.19 |
| $Al_2O_3$ | 15.05 | 13.54 | 11.93 | 12.88 | 11.23 | 13.29 | 11.92 | 10.95 |
| FeO* | 5.74 | 2.17 | 3.14 | 6.32 | 5.12 | 2.17 | 5.41 | 1.40 |
| MnO | 0.05 | 0.03 | 0.06 | 0.16 | 0.09 | 0.03 | 0.10 | 0.03 |
| MgO | 2.26 | 1.04 | 0.72 | 1.54 | 3.31 | 1.24 | 1.25 | 0.74 |
| CaO | 4.07 | 2.39 | 1.46 | 0.24 | 0.49 | 2.36 | 2.16 | 1.53 |
| $Na_2O$ | 4.09 | 4.43 | 4.93 | 0.16 | 0.15 | 2.35 | 1.09 | 0.43 |
| $K_2O$ | 1.28 | 1.19 | 0.85 | 0.46 | 1.58 | 1.18 | 1.84 | 3.17 |
| $P_2O_5$ | 0.14 | 0.06 | 0.03 | 0.14 | 0.04 | 0.05 | 0.03 | 0.00 |
| Loss | 4.07 | 1.20 | 1.79 | 2.27 | 2.66 | 2.59 | 4.14 | 3.67 |
| TOTAL | 98.97 | 100.44 | 99.16 | 98.45 | 99.36 | 99.38 | 98.45 | 99.47 |

1 Beidelman Bay Complex, rim; 2–3 Beidelman Bay Complex, core; 4–7 cycle 1a; 8 cycle 1b.

### 3. KIDD CREEK MINE AREA

We have analysed eleven rhyolite samples from the mine area and three massive sulphide samples. All of the rhyolites have flat REE patterns similar to the Uchi Lake rhyolites but have much stronger Eu anomalies (Figure 7a). The patterns show significant variations in La/Lu and La/Sm ratios which could be due to fractionation of an accessory phase in the magma chamber or mobility of the REE during alteration of the rhyolite. Two patterns (Figure 7b) are HREE-enriched suggesting the introduction of some HREE by the mineralizing solutions. Analyses of two massive sulphide samples gave LREE-enriched patterns (Figure 8) and hence failed to support this hypothesis (see also Graf 1977).

### 4. UCHI LAKE

The ore at the South Bay Mine in the Uchi Lake area is associated with rhyolite flows and a high-level quartz-feldspar porphyry intrusion. Both the porphyry and the rhyolites have the same flat REE patterns with well-developed Eu anomalies (Figure 9) and are clearly cogenetic. The porphyries are believed to be the feeder connecting the rhyolites to an underlying subvolcanic magma chamber. The existence of a subvolcanic chamber is consistent with gravity studies (Thurston, personal communication).

We have studied the effects of alteration on REE patterns by comparing analyses of unaltered rhyolites with rhyolites from the alteration pipe below the ore body. Differences between altered and unaltered rhyolites are negligible.

## DISCUSSION

MacGeehan and MacLean (1980) have argued that "calc-alkaline" rocks associated with massive sulphides at Matagami, Quebec, are actually an altered tholeiitic

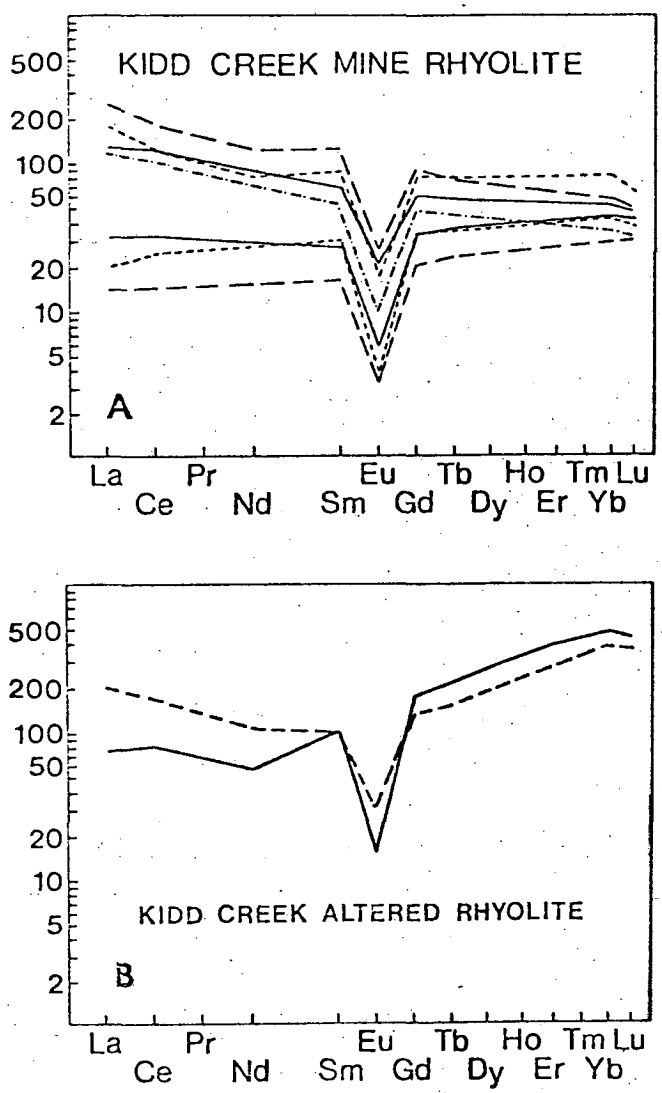


*Figure 7—REE patterns for rhyolites from Kidd Creek. **A.** moderately altered rhyolites from the mine area; **B.** highly altered rhyolites collected within a few feet of massive ore.*

sequence which, as a consequence of the alteration process, have developed the chemical signature of andesites. The Kam-Kotia sequence is similar to that described by MacGeehan and MacLean. Both consist of bimodal sequences of rhyolite and tholeiitic basalt underlain by large gabbroic sills and are clearly tholeiitic in character. This conclusion, however, does not apply to Sturgeon Lake. Both the Beidelman Bay Complex and the overlying volcanic rocks are calc-alkaline in both their major and minor element geochemistry. Thus Cu-Zn massive sulphide mineralization can be associated with calc-alkaline or tholeiitic felsic volcanic rocks. Preliminary studies of other massive sulphides suggest that the felsic volcanic rocks associated with the South Bay, Matagami and possibly the Kidd Creek deposits are tholeiitic in character whereas those associated with the Golden Grove (Western Australia) and Kuroko deposits are calc-alkaline (Campbell *et al.* in press).

Thurston (in press) has suggested that the high HREE content of the ore-associated felsic volcanic rocks may be due to the introduction of HREE by the ore-bear-

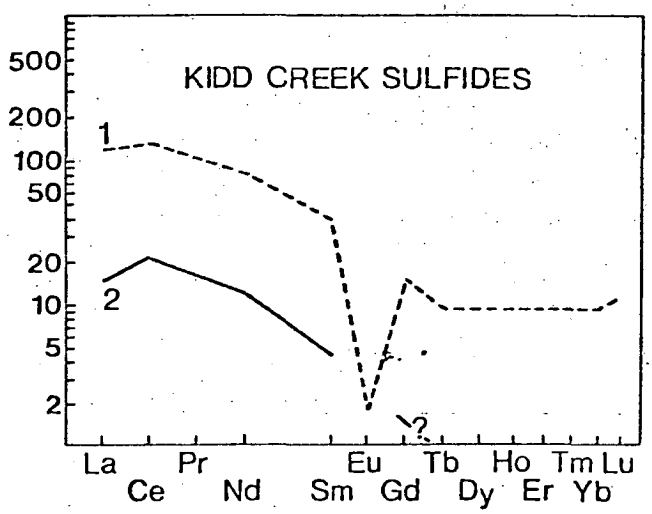


*Figure 8—REE patterns for two samples of massive sulphide from the Kidd Creek Mine area.*

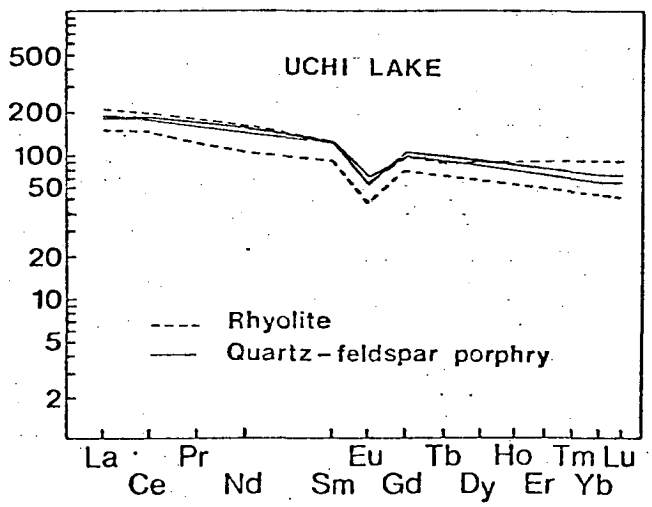


*Figure 9—REE analyses for a quartz-feldspar porphyry intrusion and rhyolite flows from the Uchi Lake area.*

ing solutions. Our study has shown that the distinctive REE patterns of the ore-bearing felsic volcanic rocks are not confined to the volcanic rocks adjacent to ores, but persist over the entire length of the ore-bearing stratigraphic unit. It seems unlikely that the ore-forming solutions could have enriched such an extensive volume of rock in the HREE. We believe that the REE geochemistry of the ore-bearing felsic volcanic rocks is a primary feature which results from a partial melting process in the crust or upper mantle and subsequent fractional crystallization.

The geochemical link between subvolcanic sills and ore-bearing felsic volcanic rocks demonstrated in this study suggests that subvolcanic sills are an integral part of the ore-forming process. The simplest explanation is that subvolcanic sills play a passive role in ore formation, acting purely as the heat engine which drives the hydrothermal system. In this model, sea water convects through the volcanic pile, producing extensive alteration of the mineral assemblage and leaching out the base metals which are subsequently re-deposited at the sea floor by submarine hot spring activity. If this model is correct, the link between ore deposits and fractionated REE patterns may be connected with the role of volatiles. Volatiles concentrate during the final stages of fractionation of a magma and, if the vapour pressure exceeds the confining pressure, explosive volcanism will result. Massive sulphides are invariably associated with pyroclastic rocks, suggesting that the role of explosive volcanism, in breaking up the volcanic pile and increasing its porosity, may be an essential requirement for ore formation.

There are two other possibilities which should also be considered, both of which require the magma chamber to play a more active role in ore formation. The first is that hydrothermal fluids derive much of their base metal content from the sill by passing through the top of the cooling magma chamber immediately following solidification of the pluton but while its temperature is still well in excess of 300°C.

The second possibility is that the ore-forming solutions are derived directly from a subvolcanic magma chamber. Volatiles and certain base metals (including Cu, Zn and Pb) behave as incompatible elements during silicate fractionation and concentrate in the residual liquid. Eventually, during the final stages of fractional crystallization, a hydrothermal fluid, rich in alkalies and certain base metals (Cu, Pb and Zn) and precious metals (Au and Ag), will separate from the silicate liquid. If the magma chamber leaks, this fluid may escape to the sea floor and form an ore-deposit. Recent isotopic studies of the Kuroko deposits in Japan (Ohmoto and Rye 1974; Pisutha-Arnond and Ohomoto 1980) suggest that the solutions which formed these ore-bodies may have contained up to 20 percent magmatic water, the remainder being sea water. Thus, if subvolcanic sills play an active role in ore genesis, most of the water involved must still be sea water which has either diffused into the magma chamber or mixed with the magmatic fluids en route to the surface. It should be noted that REE geochemistry cannot be used to distinguish between the possible roles of subvolcanic sills.

# CONCLUSIONS

It must be stressed that the results presented in this report are preliminary. Although all of the ore-bearing felsic volcanic rocks studied to date show similar distinctive flat REE patterns, it does not follow that all ore-bearing felsic volcanic rocks will have this type of REE geochemistry. Further testing is needed to clarify this point. Nevertheless it does appear that felsic volcanic rocks with flat REE patterns and pronounced Eu anomalies are prime exploration targets and we hope this information will assist mining companies in their search for massive sulphide deposits.

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New York, March 15, 1982

MEMORANDUM FOR: Messrs. W. L. Kurtz, W. D. Payne, J. C. Balla, E. W. Perkins, E. P. Bayley, D. M. Smith, Jr., R. E. Gale, R. S. Gray, A. Giesecke, P. G. Vikre, D. D. Harper, H. C. Williamson, J. Manrique, L. Montoya, J.H. Courtright

Seafloor Hydrothermal Systems

I confess with some embarrassment that it has been so long since I received the attached publication that I can't remember who sent it to me and therefore I'm sending it out to everyone. The subject is "Seafloor Hydrothermal Systems" but it focuses directly on the black smokers at 21°N, possible smoker textures in known massive sulfide ore deposits, and in one place advances the heretical concept that rhyolitic rocks are not necessary for the formation of the Noranda-type massive sulfide deposits. In addition, there are some very interesting comments on the origin of life which, if correct, may generate more interest than the concept of plate tectonics has over the past decade. Although this publication may not be relevant to your exploration programs, it is very timely and interesting and I hope you will circulate this paper to all of your staff.

F. T. Graybeal

F. T. Graybeal

Encl.

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ASARCO

Southwestern Exploration Division

October 30, 1981

FILE MEMO

Deep Fluid Penetration
and Ore Deposition

In the attached paper on processes involved in the formation of hydrothermal deposits in submarine environments, the authors propose broader applications for exhalative type occurrences. Their observations and conclusions include:

1) Fluids of primary magmatic origin are quantitatively insignificant in geothermal systems.

2) Thermally driven fluid convection systems form deposits ranging from massive sulphides to chemically enriched sediments, or widely dispersed values (veins). The latter includes gold-bearing carbonate and silicate facies iron formation (Timmins, Red Lake).

3) Such systems may include relatively immobile elements —— chromium, nickel, tungsten, tin, platinum. Some massive chromite and/or nickel deposits, previously classified as magmatic, may be exhalative-hydrothermal in origin.

4) Exploration suggestions include locating ancient hot spots beneath impermeable cap rocks.

J. H. Courtright

J. H. Courtright

JHC/sk

cc: RLB
WLK/WDP
DMS
JCB
DDHarper
REGale
RSGray
JJMerz
HCWilliamson

R. W. HUTCHINSON, W. S. FYFE, and R. KERRICH
*Department of Geology, University of Western Ontario, London, Ontario, Canada N6A 5B7*

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**ASARCO**

Rocky Mountain
Exploration Division

J. H. C.
APR 28 1978

April 24, 1978

RECEIVED
APR 27 1978
EXPLORATION DEPT.

Memorandum for: J.C. Balla
D.P. Cadwell
J.V. Desvaux
R.E. Gale
F.T. Graybeal
D.M. Smith, Jr.

Wrigglite (Ribbon Rock)

The attached papers on wrigglite (ribbon rock) from Mr. H.C. Williamson are very interesting. These deposits appear to be quite large, but relatively low grade occurrences of $CaF_2$, Be, Sn and $WO_3$.

The most common "ore" mineral at Iron Mountain, New Mexico is magnetite, and it was drilled by a major iron company in the early '40's as possible iron ore. It is, I believe, the largest known Be deposit in the U.S. The fluorite (8-12%), at this occurrence, unfortunately carries Be as an impurity, and in general metallurgy and separation is difficult. It is, however, in a tin province. The Taylor Creek tin area is just to the north and west.

Stephen Von Fay

SVF:slr
cc: TCOsborne, w/o enclosures
JHCourtright, w/ enclosures
TCWilliamson, w/o enclosures

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April 19, 1978.

Mr. S. Von Fay
Senior Geologist
DENVER OFFICE

Literature Search
"Wrigglite" (a magnetite fluorite SnO $WO_3$ bearing sediment).

Dear Mr. Von Fay:

A recent discovery of a major disseminated fluorite cassiterite wolframite deposit by Comalco at the Shephards & Murphy Mine, Moina, Tasmania (41°29.5' latitude, 146°04.5' longitude), has highlighted a distinctive rock called "wrigglite" or "ribbon rock", as a potential economic source of fluorite, tin and tungsten (see File Memo, March 13, 1978, attached).

We have recently obtained a copy of Mr. Askin's unpublished thesis entitled "Wrigglite - An Unusual Fluorite Bearing Skarn, Mt Garnet Region, North Queensland, Australia", and we attach pertinent portions. Askin, the Comalco exploration manager in Tasmania, states that Moina is the world's largest fluorite-deposit (G. Purvis, pers. com.). Askin was aware of Lost River, Seward Peninsular, Alaska deposit containing 38 Mt of 16% Ca $F_2$ and about 0.1% Sn before moving to Tasmania (Thesis, p. 37). On this basis the Moina deposit is thought to contain 40 to 50 Mt of 10% Ca $F_2$, 0.1% Sn and 0.1% $WO_3$.

Askin defines wrigglite as a fine-grained rhythmically bedded contorted sediment commonly consisting of layered magnetite fluorite idocrase with minor helvite, cassiterite, cuspidine, wolframite, scheelite, garnet and sulphide enriched zones of sphalerite, pyrite, chalcopyrite, galena and bismuthinite. Askin considers the Mt Garnet and Moina deposits, skarns, spatially and temporally associated with greisenization in the granite. However, field evidence and Purvis (pers. com.) suggest that the Moina deposit is a stratiform occurrence with no close relationship to granite. The nearest margin of the Dolcoath batholith occurs 3 km east of Moina. buried gr or por?

Mr. Askin's literature search has recognised nine wrigglite occurrences throughout the world (Page 31, Fig. 28). The occurrences within the free world are Lost River, Alaska; Iron Mountain, New Mexico; Mt Garnet, Queensland; and Moina, Tasmania.

It is of interest that Askin recognised the Moina wrigglite from personal discussion and initiated the acquisition of the ground from the Tasmanian Department in 1974 (Thesis, p. 41). At the time of acquisition, Comalco's EL 7/74 was within Asarco's EL 7/73 but the ground was a Mines Department Reserve and excluded from EL 7/73. Extensive zones of Moina Sandstone,

the host for the Moina fluorite cassiterite and wolframite, exist within EL 7/73 and these occurrences should form a prime target for exploration under the CRAE-ASARCO joint venture.

The Moina discovery emphasises the need to be aware of the potential of fine-grained banded magnetite rocks as possible host for fluorite, tin and $WO_3$ deposits and re-emphasises the instruction issued recently by Mr. Osborne to analyze samples from new prospects for unexpected elements.

Yours sincerely,

H.C. Williamson

H.C. Williamson

cc TCOsborne

Attachments: File Note dated March 13, 1978, by H.C. Williamson, titled Fluorite - Shephards & Murphy Mine, Moina, Tasmania.
P. Askin's report, pages 2 to 4 and 30 to 45, Figs. 1, 11, 16 and 28.
Assay of samples of wrigglite from Moina.

March 13, 1978.

FILE NOTE:

Fluorite
Shephards & Murphy
Moina, Tasmania.

Recently, Mr. G. Purvis, CRAE Sheffield project geologist at Burnie, Tasmania, informed me that Comalco, an aluminium company associated with the CRA group and holding E.L. 7/74 adjoining our E.L. 7/73, has made a significant fluorite discovery at Moina. The discovery was made by a Mr. Askin of Comalco who recognized the disseminated fluorite in a quartz magnetite sandstone outcropping at the site of the mill of the Shephards & Murphy mine at Moina. An inspection of the discovery site was made on Saturday, February 4, but dense forest and overgrown tracks prevent a full examination of the district.

## PREVIOUS INVESTIGATIONS

Mr. Askin has investigated disseminated fluorite deposits in Eastern Australia and has recognized and reported on a distinctive contorted and banded fluorite quartz magnetite rock which he has called "wrigglite" (Askin unpublished M.Sc. Thesis). Askin, now working out of Devonport, Tasmania, recognized wrigglite on the hillside behind the mill at Moina.

Asarco examined the Shephards & Murphy mine at Moina in 1971 while conducting a reconnaissance of Palaeozoic granites of Tasmania for Cu and Mo. Four samples (13028-13031) were collected from the Shephards & Murphy mine and analysed for Cu, Pb, Zn and Mo, but no further action was taken.

The Moina district was excluded from our original application for E.L. 7/73 as the ground was held under a special lease by the Tasmanian Mines Department but was subsequently acquired by Comalco.

Extensive investigations have been made of the Moina district and in particular the Shephard's & Murphy mines (see Appendix A) and it is significant that the occurrence of fluorite has remained undetected for so long.

## PRESENT INVESTIGATIONS

The Moina Sandstone containing the fluorite is well exposed in the bench cut made for the mill and in recently completed costeans south of the old mill site, and the Moina Sandstone occurs extensively in northern Tasmania.

The rock is a strongly contorted and banded fine to medium grained dense sandstone with alternate bands of quartz with pink fluorite and magnetite, each band varying from 3 to 8 mm in width with some irregular cross cutting veins of quartz. A petrographic description is attached.

Purvis reports that Comalco have completed an extensive drill programme (to within 500 metres of our E.L.) and have outlined a significant disseminated fluorite deposit carrying 10% fluorite and 0.1% W and 0.09% Sn. (Purvis states that Comalco considers this the world's largest fluorite deposit.)

## CONCLUSIONS & RECOMMENDATION

The disseminated fluorite deposit is a stratigraphic occurrence in the Moina Sandstone containing sub economic but possibly extractable tin and tungsten.

The extensions of the Moina Sandstone on E.L. 7/73 should be examined.

This unusual occurrence should not be neglected in exploration for fluorite, tin and wolfram sources.

We are endeavouring to obtain a copy of Paul Askin's M.Sc. Thesis from James Cook University in Townsville.

H.C. Williamson

Attachments
Appendix A - References
" B - Extract from Technical Report No. 28 by Jack Salkoski, Asarco, April 1971.
Petrographic Description.

## APPENDIX A.

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## 37 - SHEFFIELD

The northern two thirds of this sheet consists of undulating hills with good road access. The granite near Beulah and Paradise is poorly exposed but has road access. Exposure of Dalcoath granite is now partially covered by Lake Pethana. Topography in this southern portion is steeper and forestation is heavier. Hydro-electric operations have closed off areas which were formerly accessible.

Once an active area for load deposits of Sn, W, Bi, Au, Mo. The S & M Mine was the largest in the area and produced W and Bi. The All Nations and Squib Mines were also producers of W and Bi, but on a smaller scale. All had reported molybdenite in the quartz vein loads but its economic importance was marginal. The Squib Mine is still working at the present time.

on: All reported mineralisation is found in quartz veins surrounding the granite. The host rocks for these veins are quartzites and quartz porphyry volcanics and reported to be hydrothermally altered. Exposures of Dalcoath granite seen during the survey were deeply weathered and contained occasional quartz veining but no associated mineralisation. Samples taken from the S & M Mine area 13028-13031 show some quite high Cu, Zn values e.g. 910,- 220, 950 - 170, 880 - 130 ppm for Cu and Zn. The 910 value is due to chalcopyrite in quartz veining. The 950 and 880 values are from disseminated sulphides in quartzite and could be of interest, but can only be observed in a 20 foot bulldozer cut. Other samples taken at All Nations mine showed poor results although some molybdenite was present in quartz veins.

The areas around the S & M and All Nations mines has been under considerable investigation. The area prospected at the S & M mine has been covered by a 100 ft. magnetometer grid and contains several bulldozer cuts.

Wingello
S Kefhanaitiaf
Mine
Alma
Tasmania

81148 : Veined & Strongly Altered, Laminated(?) Sediment

It is possible that all the relatively quartz-rich bands in this rock are veins. However several look distinctly like laminae and these differ in appearance slightly from the more obvious veins. The "laminae" consist of granular quartz grains (up to 0.4mm in size) with minor intersticial? microcline (partly kaolinised) as well as occasional small sheaves of muscovite and erratically disseminated fluorite (10%). The "veins" are generally similar except that the quartz is heavily granulated and fluorite is more abundant (30-40%). There is some transition between the two types and if the "laminae" are indeed sandstone layers, then the veining process has also tended to effect these layers. The "veins" and "laminae" together make up around 50% of the rock.

The remaining layers and lenses consist of a murky mixture of minerals. Magnetite is present in most layers as small erratic stringers of minute subhedra. However, several magnetite-rich layers are present, one consisting of magnetite cut by minute, erratic

stringers of biotite and quartz, the other of fine to medium-grained areas (now quartz, biotite, fluorite and muscovite) set in a groundmass of magnetite.

Other layers consist mainly of large grains of garnet, commonly partly replaced by fine diopside, green hornblende and biotite, and cut by quartz/fluorite veinlets. Other layers consist simply of a fine mixture of magnetite, biotite and fluorite with or without hornblende, diopside etc.

Polished Mount: This showed up little of interest apart from the fine magnetite subhedra, often aggregated into semi-massive areas. However one medium-grained pyrite porphyroblasts, partly replaced by limonite was noted.

Remarks :

This is a complex sample but it appears to be a calcium-rich or calcium metasomatised and iron-rich meta-sediment which has been heavily veined, the metamorphic grade being reasonably high but with retrograde alteration (mainly biotite). Economic minerals were not positively identified.

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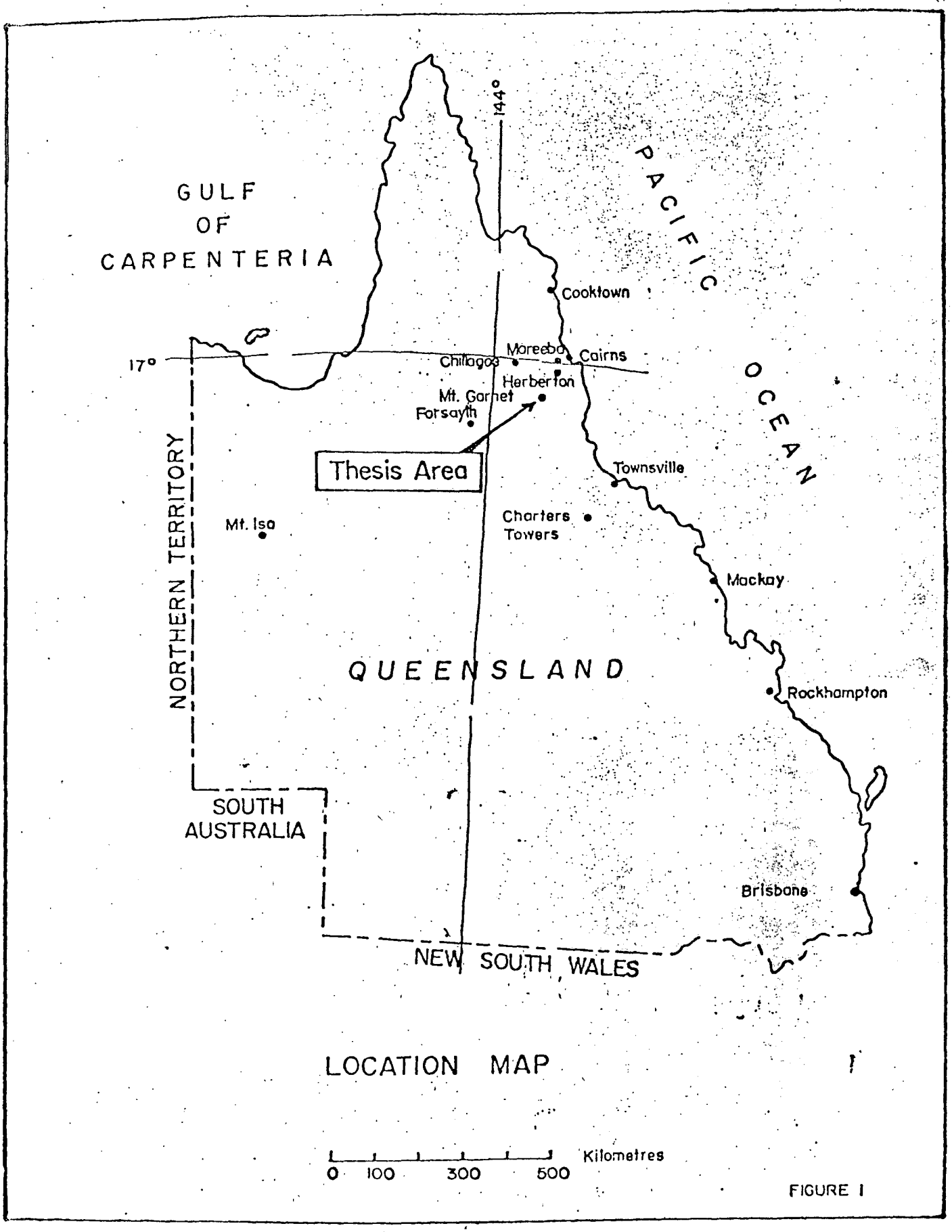
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CARPENTERIA
PACIFIC
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Cooktown
Moreeba
Cairns
Chillagoe
Herberton
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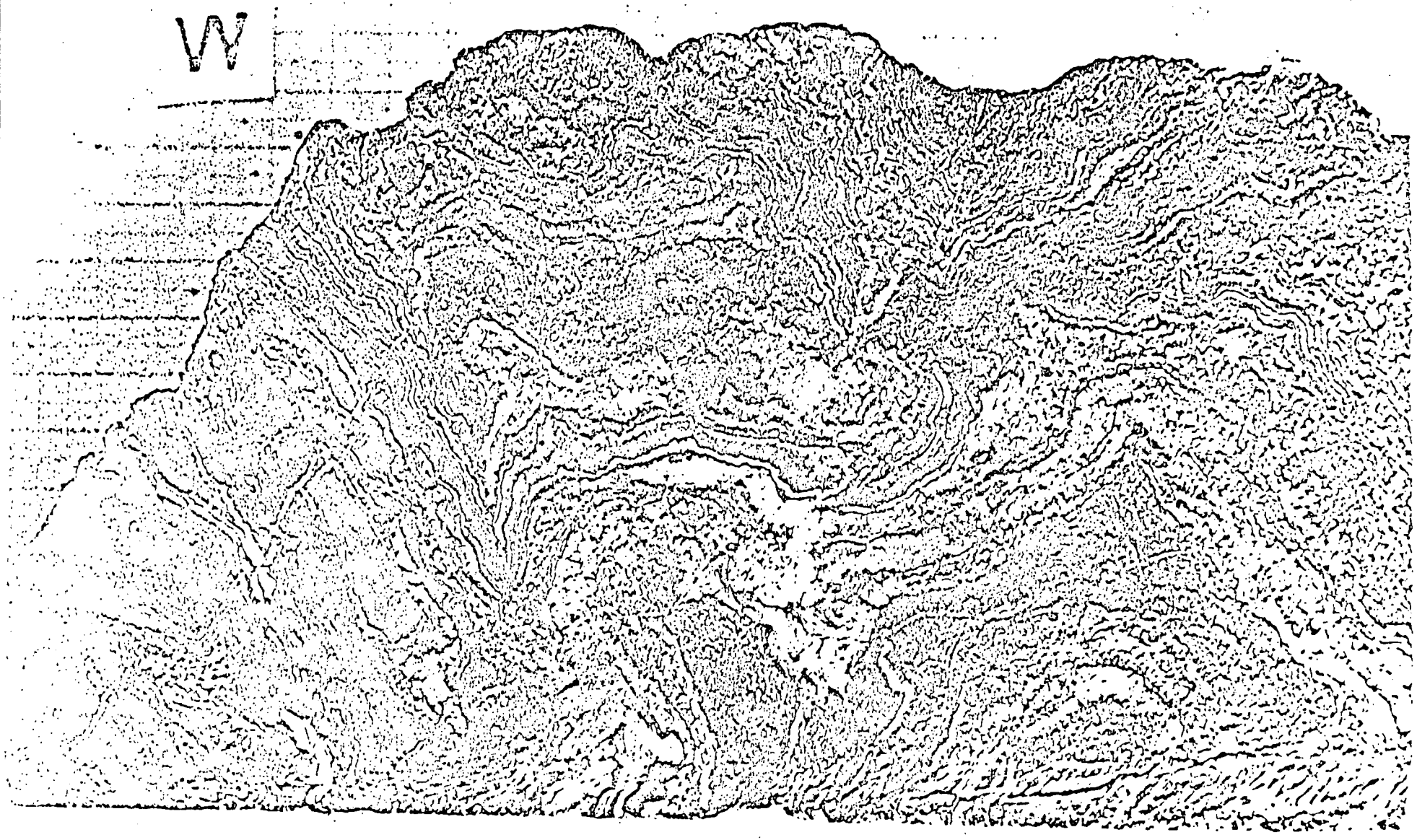
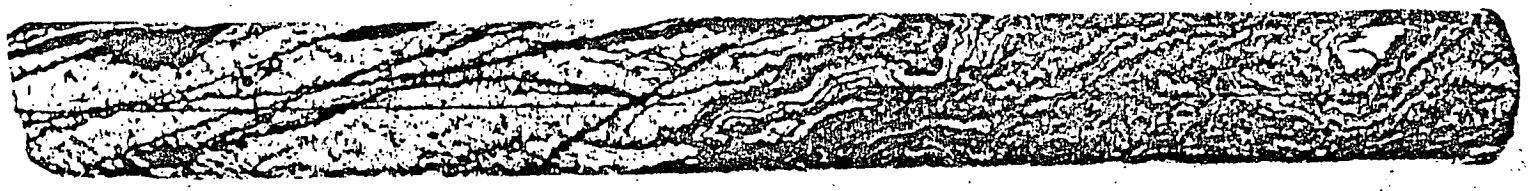
Forsayth
Thesis Area
Townsville
Charters
Towers
Mt. Isa
Mackay
NORTHERN TERRITORY
QUEENSLAND
Rockhampton
SOUTH
AUSTRALIA
Brisbane
NEW SOUTH WALES
LOCATION MAP
0 100 300 500 Kilometres

FIGURE 1

Fig 11

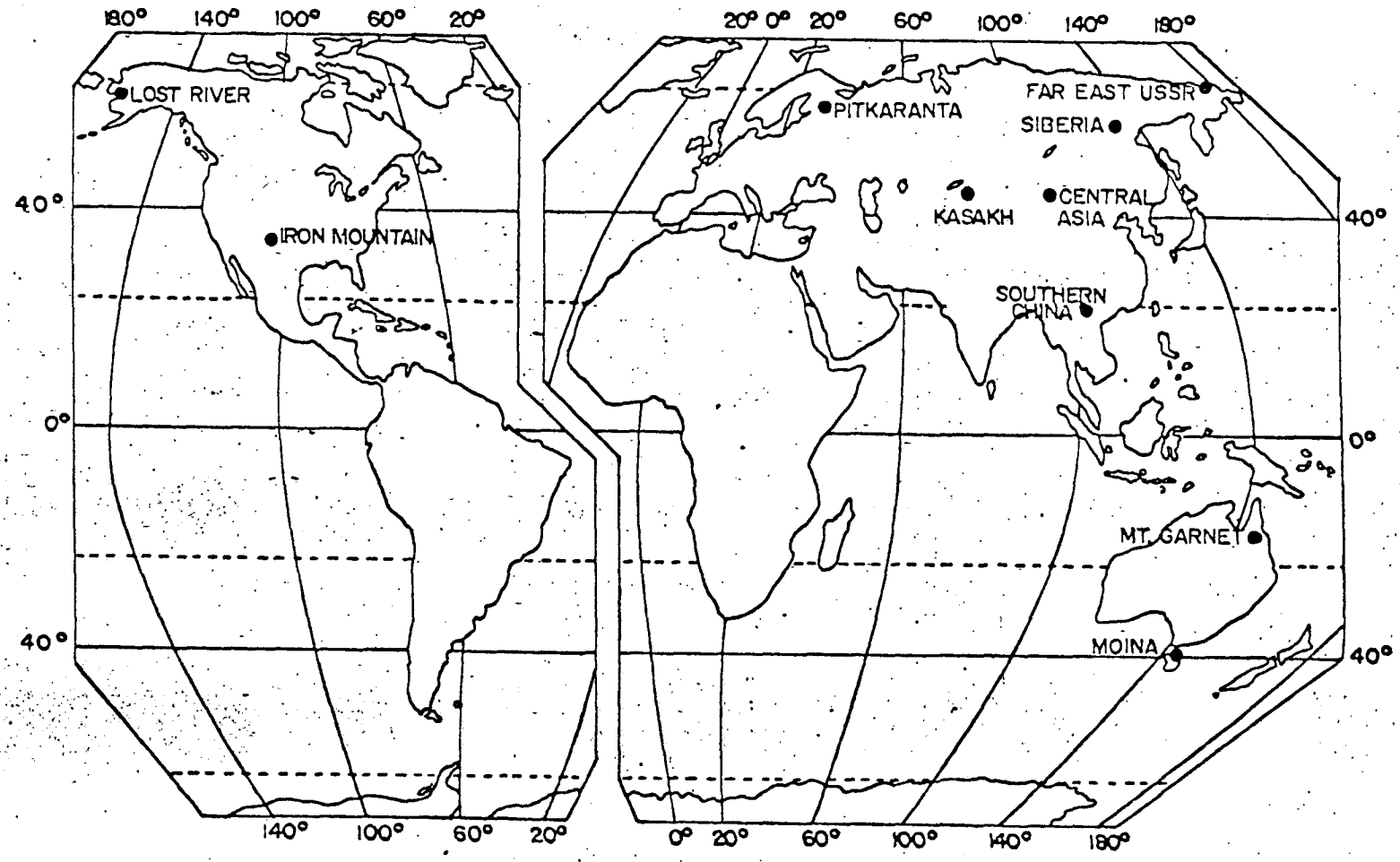




10 cm

Drill core from Llahsram deposit, Pinnacles area. PD11 at about 26.50 m.
Massive wrigglite to the right, veinlets of wrigglite in marble to the left.

Fig.16




KNOWN OCCURRENCES OF WRIGGLITE IN THE WORLD

(location of USSR, Chinese occurrences is approximate, or based on Shcherba, 1970)

Figure 28

## 5.3 Conclusion

The close spatial relationships of these altered rock types suggests that each was formed in response to the same mineralizing fluid

i.e. granite → greisen
marble → wrigglite
basalt → calc silicate rock and fluorite skarn
siltstone → hornfels

It follows that wrigglite and probably all other skarn and calc-silicate rock types formed after consolidation of the granite, not during granite emplacement. Marble formed prior to its replacement by skarn, so marmorization might have accompanied granite intrusion. Probably some of the hornfelses formed also during granite intrusion. It is possible that only the bleached zones in the siltstone hornfels were formed at the stage of wrigglite formation.

# CHAPTER 6

## KNOWN WRIGGLITE OCCURRENCES IN THE WORLD

### 6.1 INTRODUCTION

At least nine wrigglite occurrences apart from those at Mt. Garnet have been reported throughout the world. In approximate order of discovery the localities are:

1. Pitkaranta, USSR.
2. Lost River, Alaska, U.S.A.
3. Iron Mountain, New Mexico, U.S.A.
4. Kazakh, USSR.
5. Siberia, USSR.
6. Southern China (People's Republic)
7. Central Asia, USSR.
8. Far East (Siberia) USSR.
9. Moina, Tasmania, Australia

The locality of each of these is plotted on Fig. 28. A summary of the geology and nature of the wrigglites in each locality follows.

### 6.2.1 PITKARANTA, USSR.

#### Introduction

In this area is the first described wrigglite occurrence. The area is on the east side of the Lodoga Sea, now part of the USSR., but at the time of the discovery, about 1903, was part of Finland. The deposits were discovered by O. Trustedt, a Finnish mining engineer and geologist. The occurrence is described in detail by Trustedt (1907) and reviewed by Eskola (1951).

#### Geology

The structure of the area is characterized by gneiss domes of Precambrian age, overlain by a sequence of metasediments: marble, calc-silicate rocks, amphibolite, dolomitic marble and mica schists. This complex is sharply cut by Precambrian Rapakivi granite, with which fluorite-tin-base metal mineralization in the area is associated. The geology of the mineralized field is shown on Fig. 29.

The Rapakivi granite is characteristically a porphyritic

leucocratic granite, having accessory fluorite, as much as 0.36% F. An analysis of a composite mixture of 54 samples (in Eskola, 1963) is given in Appendix 3. A granitic aplite, a differentiate of the Rapakivi granite, often with much finely disseminated violet fluorite, occurs in many places. It shows that the granite probably underlies the ore fields at shallow depth.

The mineralization characterisitic of each of the areas on Fig. 29 is as follows:

a) Old Mining Field: Cassiterite and magnetite, chalcopyrite and sphalerite, in cavernous diopside-grossularite/andradite skarn, which replaces marble.

b) Ristaus and New Mining Field: Serpentinization, and magnetite-chalcopyrite-sphalerite-cassiterite mineralization of dolomitic marble. The serpentinization is extensive.

c) Hopunvaara: Wrigglite pipes and veins in dolomite.

d) Lupikko: Beryllium bearing idocrase and helvite within variegated skarns.

The Hopunvaara wrigglite occurrences:

Trustedt found wrigglite in a marble quarry within 30 m of the contact with Rapakivi granite. He referred to them as ore pipes. They resemble tree stems often branching, growing through the marble. They have concentric structure and consist of alternating dark layers mainly of magnetite and light layers of idocrase and fluorite. Occasionally greenish garnet occurs instead of idocrase and some sulphide minerals accompany the magnetite. Serpentine is occasionally found in the pipes indicating the serpentinization of the dolomite preceded formation of wrigglite. The sequence of formation of the wrigglite according to Trustedt is shown in Fig. 30.

Trustedt's paper contains numerous photographs and diagrams of "ore pipes" showing identical texture and structure to the Mt. Garnet wrigglites.

The serpentinized dolomite in the area often has a concentric rhythmic layered structure; serpentine and dolomite alternate in layers 1 mm to 5 mm thick. Trustedt called this texture Eozoon structure because the so called 'Eozoon" were once thought to be fossils. Photographs of the material in Trustedt's paper look like flow banded rhyolite, and have similar texture to the layered

cuspidine skarn at Mt. Garnet, which may be therefore texturally analogous. In places there is apparently evidence that the serpentine is an alteration of diopside.

The Lupikko beryllium bearing skarns:

Various skarn types occur here, from massive types to rhythmically layered veins of wrigglite type. The main granite body outcrops about 3 km away, but is probably not far below because a dyke of aplite and tourmaline bearing pegmatite occurs in the mine at Lupikko.

The aggregate size of the variegated skarn bodies is small, about 10 x 100 m. They were mined in various parts for iron or for tin and base metals. The replaced rock is dolomitic marble. Serpentine is abundant, and fluorite and idocrase common. Helvite occurs occasionally as tetrahedra together with idocrase. Eskola (1951) reports up to 1.25% BeO in the idocrase.

### 6.2.2. LOST RIVER, ALASKA

Introduction

This wrigglite occurrence was found in 1907, soon after the Pitkaranta occurrence by A. Knopf of the U.S. Geological Survey. It is in the central York Mountains, Western Seward Peninsula, and is described by Knopf (1908). Later reports which deal in more detail with related mineralization of the area are Steidtmann and Cathcart (1922), Sainsbury (1964 a, 1964 b, 1969), Brown (1973).

The Lost River area is the site for the potentially largest fluorite mine in the world - reserves of over 38 million tonnes exceeding 16% $CaF_2$ and about 0.1% Sn have been blocked out by drilling by the Lost River Mining Corporation (McOuat, 1973).

Geology

In the central York Mountain, argillaceous limestones and limestones of Ordovician age are thrust northward over slates and argillaceous limestone of pre-Ordovician age. Late Cretaceous stocks of biotite granite cut the thrust plates. Dykes of granite, rhyolite porphyry and lamprophyre were later injected along normal faults which in part post-date the granite stocks. Ore deposits of tin, beryllium and fluorite were formed shortly after, probably from solutions derived from the granite at depth.

The mineralization in the area is of several inter-related types:

a) Greisen deposits: Most deposits consist of cassiterite bearing topaz greisen formed by replacement of granites and lamprophyre and rhyolite porphyry dykes. The largest deposit is the Cassiterite Lode, Zone 1 Fig. 31, which is greisenized quartz porphyry, 2 m to 4 m thick and about 3000 m long.

b) Skarn deposits: These exist only within about 300 metres of granite contacts. Skarn occurs in the Lost River Tin Mine (the Cassiterite Lode), in the lower levels near a granite cupola. The granite does not reach the surface. Skarn also occurs at Tin Creek, Zone 4 Fig. 31, surrounding the granite boss. The variation in skarn types has not been described, but "banded tactite" is mentioned in the drill logs by Sainsbury (1964) in the Lost River Tin Mine, and wrigglite at Tin Creek has been described in detail by Knopf. According to Steidtmann and Cathcart (1922) skarn surrounding the other granite bosses in the region consists chiefly of massive unlayered green hornblende, pyroxene, idocrase and minor fluorite.

c) Replacement veins, stockworks: Veins and veinlets chiefly of fluorite, but usually containing high concentrations of beryllium minerals, occur in several zones, mainly as replacements of limestone. Most zones lie along the Rapid River Thrust, (Zones 3, 4, 6, 7 Fig 31).

The largest deposit is a stockwork surrounding the Cassiterite Lode-this is the main zone, Zone 1, of the Lost River Mining Corporation's fluorite reserves. It contains only trace concentrations of beryllium.

The largest beryllium bearing stockwork is at Camp Creek, (Zone 2 on Fig. 31). Most of the vein material contains BeO in the range 0.3 - 1.75%. About 1 million tonnes of +0.2% BeO had been indicated by private companies up to 1964 (calculated from Sainsbury, 1969), but the zone or zones where these reserves have been indicated is not stated. The beryllium mineral is mainly very fine grained chrysoberyl. These veins are commonly finely layered and texturally resemble wrigglites.

Wrigglite occurrences

The main locality for wrigglites is Tin Creek; however the stockwork veins often show wrigglite like texture.

Tin Creek: Knopf (1908) refers to the wrigglite mineralization here

as "orbicular contact metamorphism". The wrigglite occurs chiefly as pipe-like shapes composed of "an alternating succession of black and white bands, commonly a millimeter or so in breadth". (Knopf, 1908). The mineral composition in order of abundance is fluorite, hornblende, idocrase, plagioclase ($Ab_3An_7$)and magnetite. The light layers consist of mutual intergrowths of fluorite and plagioclase, and the dark layers fluorite with hornblende and/or idocrase and commonly some magnetite. Sainsbury (1969) reports that there is as much as 0.45% BeO in the rock. It is present as helvite grains up to 2 mm in diameter, commonly in the magnetite layers. The idocrase has a tendency to form radial groups of short stout columns. The central part of the pipes contains coarser calcite-idocrase-fluorite-hornblende or fluorite-idocrase-hornblende. The pipes interfere with one another to some extent causing wrinkling of the otherwise relatively even layering. Pipes extend outward from symmetrically layered veins, which have wrigglite texture and which cut through the marmorized limestone. These veins are not of quite the same composition as the pipes. They consist of fluorite, calcic plagioclase ($Ab_1An_2$) with pyroxene, green mica, hornblende and minor arsenopyrite, cassiterite and scheelite.

The geology of the Tin Creek area is shown on Fig.32. Limestone surrounding the granite boss has been marmorized and all skarn occurs either at the granite contact, or nearby along fractures.

Wrigglite textures in stockwork veins: The best described example of a stockwork deposit is Zone 1, surrounding the Cassiterite Lode. A diagrammatic representation of this stockwork is shown in Fig. 33. The Cassiterite Lode, which is 2 to 3 meters thick and extends for about 3000 meters along strike, is a porphyry in which tin ore is localized, especially in brecciated greisenized parts.

The veins making up the stockwork vary in thickness from microscopic size up to 30 cm. They vary in mineralogy and contain fluorite, amphibole, plagioclase, zinnwaldite, topaz, and tourmaline as the main constituents. The most abundant types of veins in the stockwork are dark green delicately layered veins, referred to as tactite veins by Brown (1973), and delicately layered white veins. Both are similar texturally to wrigglites and have layers about 1 mm thick, but the mineralogy of each is different. The tactite veins

consist of green fluorite, magnetite and pyroxene. Minor cassiterite occurs in the tactite veins; some is an exsolved phase within magnetite. Locally pyrite and pyrrhotite "replace the magnetite bands or even ..... selectively replace one or two bands within a multi-banded vein" (Brown, 1973). The white veins consist of white fluorite and sericite.

In the beryllium bearing stockworks (e.g. Camp Creek, Zone 2) the veins are finely layered, consisting of imperfectly rhythmic 1 - 2 mm layers of fluorite, and fluorite intergrown with diaspore, mica, tourmaline and very fine grained chrysoberyl. (Sainsbury, 1969)

### 6.2.3 IRON MOUNTAIN, NEW MEXICO, U.S.A.

#### Introduction

This occurrence of wrigglite was first described in detail by Jahns in 1944. He was part of a team from the US Geological Survey examining the possibility of the existence of beryllium mineralization in the pyrometasomatic rocks which had been previously known in the area. Jahns refers to the wrigglite as "ribbon rock".

#### Geology

A thick section of Carboniferous limestone is intricately cut by Miocene plugs, sills and dykes of rhyolite and aplitic granite. Contact metamorphism consists of marmorization of the limestone and formation of hornfels from the more argillaceous beds. Metasomatism has produced calc-silicate rocks and two types of skarns. The calc-silicates, quartz-pyroxene-clinozoisite-plagioclase rocks, were formed from less pure calcareous rocks. The skarns are wrigglites and massive-bedded magnetite-andradite rocks.

The magnetite-andradite skarn contains hedenbergite and hematite in local abundance, and other minerals in minor amounts including fluorite, scheelite, powellite, willemite and iron and base metal sulphides. It occurs as replacements of marble in bodies ranging in size up to millions of tonnes. The bodies are generally tabular conforming crudely to the bedding of the adjacent sedimentary rock. They do not always occur adjacent to the igneous intrusions.

#### "Ribbon rocks"

Two distinctive types of wrigglites occur: a dark beryllium

[illegible], and a lighter coloured variety with less magnetite. [illegible] beryllium rich variety has wavy magnetite laminae 0.2 [illegible] mm thick, with much thinner intervening layer aggregates of [illegible], helvite, and locally quartz. Irregular masses of adularia [illegible] in the less strongly layered parts of the rock. The helvite [illegible] pale-red to amber coloured crystals and crystalline [illegible], closely resembling garnet. The rock occurs in areas of [illegible] thick pods, pipelike masses, and thin tabular masses of [illegible] of a metre to several metres thick.

[illegible] widespread lighter coloured variety has less magnetite [illegible] hematite. The light coloured layers contain colourless [illegible] fluorite, green biotite and chlorite, and pale [illegible] green prismatic idocrase. There is also minor [illegible], helvite and danalite (both almost identical in [illegible] to the grossularite), diopside, clinozoisite, quartz, [illegible] and graphite. Crystalline pods and druses with concentric [illegible] of "ribbon rock" surrounding them are common; they and the [illegible] surrounding layers consist chiefly of fluorite with minor [illegible], helvite, quartz and felspar. The rock occurs as [illegible] particular bodies, trending parallel with the strike of the [illegible] lens. It has a tendency to occur between massive garnet-[illegible] skarn and the nearest intrusive contact as shown in Fig. [illegible]

[illegible] paper contains many photographs of the "ribbon rocks". [illegible] texturally identical to the Mt. Garnet wrigglites.

[illegible] USSR.

[illegible]

The first reference to this in English is Beus (1966). It is [illegible] described in English by Zasedatelev (1973). Zasedatelev does [illegible] the location of the wrigglites he describes, but Beus [illegible] quotes the work of Zasedatelev on beryliferous skarns in [illegible] and his descriptions tally perfectly with Zasedatelev's [illegible] reality. All the following data is either from Beus or [illegible]. The exact location within the Kazakh Republic is not [illegible]

[illegible]

[illegible] region is composed of Middle and Upper Devonian [illegible] and pyroclastic rocks, which have been metamorphosed

and steeply folded and intruded by alaskite granites. The granite contains fluorite as an accessory mineral, and, especially in areas close to skarn mineralization, the marginal parts are greisenized. The granite is cut by veins of pegmatite, aplite, and quartz which in places contains wolframite. The sedimentary rocks are predominantly sandy, sandy-clayey, and tuffaceous, now metamorphosed to various types of hornfels. Conglomerates and marble occur in layers and lenses.

A zone of metasomatized rocks about 100 m thick and 5 - 6 km long extends parallel to the strike of the sedimentary rocks. Skarns are arranged in conformable lens-shaped bodies with sharp or gradational contacts. The most prevalent skarn types are, in order of abundance;

1) Fluorite - garnet rocks containing idocrase.
2) Micaceous - fluorite- magnetite rocks containing chrysoberyl
3) Micaceous-fluorite - magnetite rocks containing felspar
4) Garnet-fluorite - magnetite rocks containing idocrase

Gradations between these types and varieties of these types are common.

The fluorite-garnet skarn is usually somewhat massive and granular; in places it is layered. The garnet is chiefly grossularite and less commonly andradite. Locally abundant are hematite, idocrase, felspar (orthoclase, albite) and sulphides (sphalerite, chalcopyrite, galena, molybdenite).

The micaceous-fluorite-magnetite skarns containing chrysoberyl are fine grained rocks with thin layered structure. The width of the layers is most commonly about a few tenths of a millimetre. The dark layers are composed of magnetite and hematite and light layers of fluorite, mica and chrysoberyl. The chrysoberyl occurs as very fine grained plates of the order of hundredths of a millimetre thick and 0.05 to 0.1 mm long. The Be content of the skarn is from 0.14 to 0.25%. Spherical and lens shaped geode-like cavities generally up to a few centimetres across are common - they contain mostly violet fluorite and a little mica, and in places minerals foreign to the enclosing rock, such as scheelite, cassiterite, beryl, helvite, phenacite, epidote, and sulphides. The layering in the skarn is conformable with the edges of the geodes.

The micaceous-fluorite-magnetite skarns containing felspar have a coarser and more distinct lamination. The mica is a

greenish ferromuscovite and the felspar mostly orthoclase. With increasing content of mica, felspar content decreases and topaz appears. The beryllium content is insignificant.

The garnet-fluorite-magnetite rocks with idocrase are dark grey and finely laminated. The dark layers consist of magnetite and fluorite and the light layers of idocrase. The idocrase occurs as small radiating columns. Geodes similar to those above are common - they are filled predominantly with garnet and fluorite. The idocrase is beryllium-bearing with a BeO content reported to be up to 5% ? ("50%" in Beus - probably a typographical error).

The average chemical composition of the wrigglites is shown in Table 3, together with the composition of Mt. Garnet wrigglites for comparison.

Zasedatelev's paper contains a photo of the finely banded skarns, which he lists as "collomorphic segregations". They are identical in texture to the Mt. Garnet wrigglites- the layering is wavy, rhythmic but imperfect, and "unconformities" in the layering are conspicuous.

### 6.2.5 SIBERIA, USSR.

#### Introduction

The presence of wrigglites in Siberia is first reported in English in a paper by Getmanskaya (1972). The exact location is not stated. It is described only as "a Siberian polymetallic district, where the late fluorine mineralization is widespread and common". Shcherba (1970) shows a locality of beryllium bearing greisens in Siberia- this locality is possibly the one referred to by Getmanskaya. It is plotted on Fig. 28.

The following descriptions of the geology and mineralization are necessarily vague because of the sketchy nature of Getmanskaya's paper.

#### Geology

The area is made up of regionally(?) metamorphosed Lower Paleozoic sedimentary rocks and a sequence of Jurassic and Tertiary sedimentary rocks. Dolomite and dolomitic limestones are common. Three intrusive magmatic complexes of Permian, Triassic and Jurassic ages, occur. The complexes range from quartz diorites to leucocratic granites: each complex is mineralized, with a reported increase in intensity of mineralization with decreasing age. The

area is a beryllium metallogenic province.

Greisenization is characteristic in each complex. The greisens are apparently vein-like, and consist of quartz-topaz-muscovite or quartz-muscovite, both with accessory beryl.

At least one ore deposit, which is mined presumably for lead, zinc and beryllium, occurs in the district - it occurs at a "considerable" distance from a granite massif belonging to the youngest complex, and lies in a body of Lower Paleozoic metamorphosed limestone, dolomitic limestone and mica schists which have been intensely fractured and intruded by veins of leucocratic granites and a stock of quartz diorite. Presumably a granite massif lies at shallow depth below the deposit. The ore zone is a system of vein/veinlets with an overall lens-like or pipe-like outline, and with a vertical span of 300 m. The composition of the veins and veinlets is very variable but partly dependent on depth and the nature of enclosing rock. Fluorite is ubiquitous in the veins, and other minerals are chlorite, sericite, tourmaline, albite, epidote, sulphides (chiefly pyrite, arsenopyrite, sphalerite and galena), and beryllium minerals. The nature of beryllium mineralization depends on the host rock - it is bertrandite, phenacite, beryl, euclase in granite or in schist host rock; phenacite and helvite in basic aluminosilicate rocks like skarn and diorite; and phenacite and chrysoberyl in the dolomitic limestone and dolomite host rocks. Apparently none of the veins exhibit wrigglite textures as at Lost River with the possible exception of some parts of the chlorite-sericite-fluorite veins which are "festoon banded", and medium or coarse grained. Skarn occurs in the ore zone - it is composed of diopside-garnet or idocrase-garnet but is apparently massive and not layered.

Wrigglites, however, occur in the exocontact zone of the granites of the youngest complex. They occur amid bedded dolomitic limestones, calcareous shales and micaceous shales. They are "fine grained with an odd kind of thinly banded structure" and are composed of fluorite-idocrase-magnetite. Small crystals of chrysoberyl and rarely helvite are present. The idocrase is beryllium bearing. No other details of the wrigglites are given.

### 6.2.6 SOUTHERN CHINA (PEOPLE'S REPUBLIC)

Beus (1966, p. 33), refers to a rare beryllium mineral,

taafeite ($Al_4BeMgO_8$), described by Chinese investigators from the south of the Chinese People's Republic. The only relevant reference is "in association with chrysoberyl and spinel in thin-banded metasomatic rocks in the exo-contact zone of a mass of greisenized beryllium bearing granites in contact with a limestone dolomite mass". This clearly seems to be a wrigglite locality, but no other references to this deposit could be found.

### 6.2.7 CENTRAL ASIA, USSR.

Beus (1966, p. 52) lists an occurrence in "Central Asia" of magnetite-fluorite skarns with helvite, danalite, idocrase, pyroxene, but he does not describe the deposit in the text. It is possibly a wrigglite occurrence. No references in English describing the deposit could be located.

### 6.2.8 FAR EAST, (SIBERIA) USSR.

Introduction

Sainsbury (1969) refers to a paper, written in Russian, by M.M. Govorov (1958) (Specific features of mineralogy and genesis of tin-beryllium-fluorite deposits of the Far East. Akad. Nauk. SSSR Izv. Ser. Geol. no. 1:62-73). Shcherba (1970, p. 243, 244) mentions the same deposits. The mineralized area is possibly adjacent to Alaska, over the Bering Sea, where the geology is similar to the Lost River area.

Geology

The only details which Shcherba gives about the geology and mineralization are contained in a table, reproduced here as Table 5. Thinly layered textures in veins and skarns are mentioned, and so it is clear that wrigglites occur in the area.

### 6.2.9 MOINA, TASMANIA

Introduction

Wrigglite was first recognized in this area following a personal discussion with J. Paul McKibben. He recognized that rocks with similar texture to the Mt. Garnet wrigglites occurred in drill cores at Moina, Northern Tasmania. His company, Consolidated Goldfields of Australia, had been searching in that area for tin ores several years ago. The presence of wrigglite was subsequently confirmed in surface outcrops and in the cores by staff of the Commonwealth Aluminium Corporation Ltd. The area is now being investigated for its potential for fluorite ores. Details of the

extent and nature of the wrigglites are not yet known. The regional geology has however been described by Jennings, (1965).

Geology

A sequence of Ordovician rocks - conglomerate, sandstone and limestone - folded into E-W trending folds, lies over a Precambrian metasedimentary basement. Two petrologically distinct granite bodies, the Dove and Dalcoath Granites, of Devonian age, intrude these rocks. The Dalcoath Granite is "tin bearing", and apparently most mineralization in the district is associated with it.

The most common mineral deposits contain tin-tungsten-bismuth and there are lesser gold, silver, lead and zinc deposits. Mines in the area were small. The largest was the Shepherd and Murphy Mine which in the late 1800's produced about 550 tonnes of Sn, 240 tonnes of $WO_3$ and 70 tonnes of Bi. If all mineralization in the area is associated with the Dalcoath granite a distinct zoning occurs with gold, silver and base metals more distant from the granite, as illustrated in Fig. 35.

Near the Dalcoath granite, the limestone has been contact metamorphosed and metasomatised to garnet-pyroxene skarn and wrigglite.

Wrigglite occurs at the Shepherd and Murphy Mine. Here the orebodies are six roughly parallel quartz veins up to 50 cm in width, 400 m long and about 100 m deep. They are steeply dipping, cutting sandstone and limestone. The veins carry wolframite, cassiterite and bismuthinite, in a gangue of quartz with minor fluorite, topaz and beryl. Where the veins cut limestone, massive skarn and wrigglite occur.

Much of the wrigglite is very fine grained and almost black. It resembles basalt at first glance, and has possibly previously been confused with Tertiary basalt which covers much of the area. The fine layered texture shows best on weathered surfaces. Determination of the mineralogy of the wrigglite is difficult because of its fine grain-size. The main constituents are magnetite, fluorite, and idocrase(?) (biaxial, low birefringence, colourless- the properties agree with idocrase, but it could also be epidote, or cuspidine). Wrigglite from this area assays from 5 to 10% F.

CHAPTER 7

## ROCKS WITH SIMILAR TEXTURES TO WRIGGLITES

Finely layered textures are common in rocks. Apart from those formed by flow banding or sedimentary layering or undisputed encrustification, the rock types with similar textures include: a) agates, jasperoids. b) parts of so-called epithermal gold-silver deposits. c) an occurrence of magnetite at Vancouver Island. d) a rare example of layered skarn at Calcifer, North Queensland. Some notes on each of these are

a) Agate, Jasperoids These rock types are the most obviously similar in appearance to the hand-specimen appearance of wrigglites. Lindgren and Loughlin (1919) describe such rocks from the Tintic Mining district U.S.A., and were amongst the first to postulate that the origin of the layers was due to Liesegang type diffusion.

b) Epithermal gold-silver deposits These small complex vein-like orebodies are renowned for their rich gold and silver content and are thought to form close to the surface where rising hydrothermal solutions are rapidly chilled by circulating meteoric waters. 'Colloform' textures are commonly reported. Kieft and Oen (1973) report that in telluride-bearing gold-silver ores of Salida, Indonesia "not all banding is due to encrustation. The sulfide-rich bands often show a microscopic internal banding due to variation in grain size and the concentration of sulfides and carbonates in thin, often rhythmically spaced diffusion zones". The author has seen what can only be diffusion layers in epithermal gold ore specimens from Placer, Mindanao, Philippines: concentric layers rich in pyrite occur inwards from fractures within severely argillized andesite, as this sketch, Fig. 36, illustrates

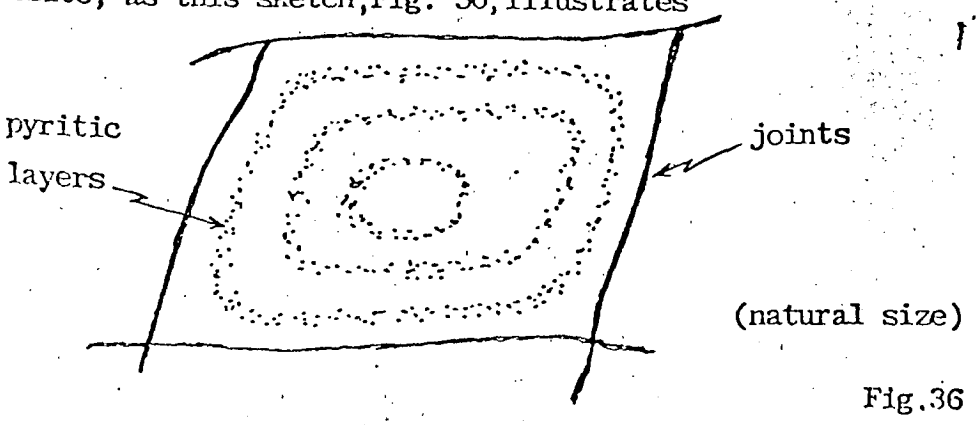



Fig.36

c) Magnetite, Vancouver Island Stevenson and Jeffery (1964) describe 'colloform' magnetite in a contact metasomatic iron deposit from this locality. It takes radiating botryoidal forms, nodular masses, within pipelike orebodies in limestone close to a dioritic stock. It may be similar in both appearance and genesis to wrigglites.

d) Skarn at Calcifer, North Queensland (about 40 km south of Townsville) The author noticed a specimen of layered skarn, collected by a student, in a laboratory at J.C.U.N.Q's Geology Department, and subsequently visited the collection site. The rock consists of contorted dark layers of disseminated very fine grained chalcopyrite, ? bornite and ? chalcocite in matrix of fine grained white calc-silicate mineral (possibly pyroxene). It occurs only very locally within a vein like zone of skarn about 4 m across in a limestone quarry. Granodiorite outcrops nearby. Skarn types with textures like this seem to be rare throughout the world.

In all the cases quoted here the layering is relatively simple mineralogically compared to wrigglite, but in each case the layering can be explained by diffusion processes.

# CHAPTER 8

## FAVOURABLE LOCALITIES FOR THE OCCURRENCE OF WRIGGLITE IN THE WORLD

Sainsbury (1964) considered that several geological associations were favourable for the occurrence of beryllium deposits of the Lost River Type. These associations are:

"1. Tin deposits with biotite granite
2. Limestone near granite
3. Abundant fluorite in or near the tin deposits
4. Topaz greisens containing cassiterite ... etc.
5. Beryllium in skarns around the granites, or of beryllium minerals in the granites or associated tin deposits."

Table 6 lists all the similarities of wrigglites. From this table it is apparent that Sainsbury's association are also favourable for the occurrence of wrigglite. The only modification which seems to be necessary to Sainsbury's list is the emphasis on tin deposits. The Iron Mountain area is not noted for its tin occurrences, yet wrigglite occurs there. That the area is a metallogenetic province of fluorite plus tin and/or tungsten and/or beryllium, is the best criterion.

Sainsbury also lists specific localities in the world which he believed to be favourable for such deposits. Possibly the most likely place to find wrigglite is Thailand (not listed by Sainsbury) and Malaya, where fluorite and tin deposits in limestones are abundant.

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REF: 9320 ORDER NO. 0985 14/4/78

| SAMPLE NO | CU | PB | ZN | AG | W | AU | SN | F | $U_3O_8$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| 93305 | 10 | <10 | 180 | <1 | 950 | <0.05 | 301 | 4.8% | | Wrigglite Mound |
| 93306 | 30 | <10 | 180 | <1 | 500 | <0.05 | 193 | 4.4% | | |

ALL RESULTS PPM EXCEPT WHERE NOTED