

Partition of Uranium in Four Canadian Examples  
of Mississippi Valley Type Base Metal Deposits:  
Pine Point, N.W.T.; Polaris, N.W.T.; Newfoundland  
Zinc, Newfoundland; and Gay's River, Nova Scotia

by

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## ABSTRACT

Fission track analyses of minerals and host rocks, and fission track mapping of uranium in samples from four Canadian Mississippi Valley type deposits, indicates that uranium concentrations in these samples are very minute (0.001 - 8.4 p.p.m.). The lowest values are found in the sulfides (galena 0.04 p.p.m., sphalerite 0.03 p.p.m., marcasite 0.06 p.p.m.). Sparry carbonates vary within three orders of magnitude (0.01 to 8.4 p.p.m.), while fluorite and pyrobitumen are very poor in uranium. The host rock dolostones contain generally more uranium than the ores (ca. 1.0 p.p.m.). Impurities within the host dolostones contain relatively higher concentrations (up to 5.56 p.p.m.).

These results are unexpectedly low, in light of recently published values for sulfide minerals from other environments.

Physio-chemical considerations would suggest that, if available, uranium should have precipitated in spatial association with the metallic sulfides. The extremely low values encountered suggest that the ore forming fluids did not have access to an appreciable supply of uranium.

Economic concentrations of uranium in Mississippi Valley type deposits appear, therefore, unlikely. The coincidence of the numerous physical and chemical requirements for such a concentration might be met only in exceptional circumstances.

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## INTRODUCTION

Mississippi Valley-type deposits (herein referred to as M.V.T.D.) are stratiform lead, zinc, barite, fluorite, occurrences hosted by carbonate rocks. They represent one of the most thoroughly investigated types of mineral deposits known. Peculiarly, there exists no previous research on the distribution of uranium in such deposits. The documentation of this distribution and the likelihood of such an affiliation is the subject of this thesis.

### Scope and Purpose

This thesis addresses itself to three questions:

- 1) What is the quantitative distribution of uranium in four M.V.T.D.?
- 2) Where does this uranium occur?
- 3) Based on the results, what is the likelihood of uranium occurring in economic quantities in M.V.T.D.?

In a study of this nature, a large variety of possible subject deposits were available. Of those which occur in Canada, four were selected: the Pine Point deposit, N.W.T., the Polaris deposit, Little Cornwallis Island, N.W.T., the Newfoundland Zinc deposit, Daniels Harbour, Newfoundland, and the Gay's River deposit, Nova Scotia. Their locations are shown in Fig. 1.

These four particular occurrences were selected for three main

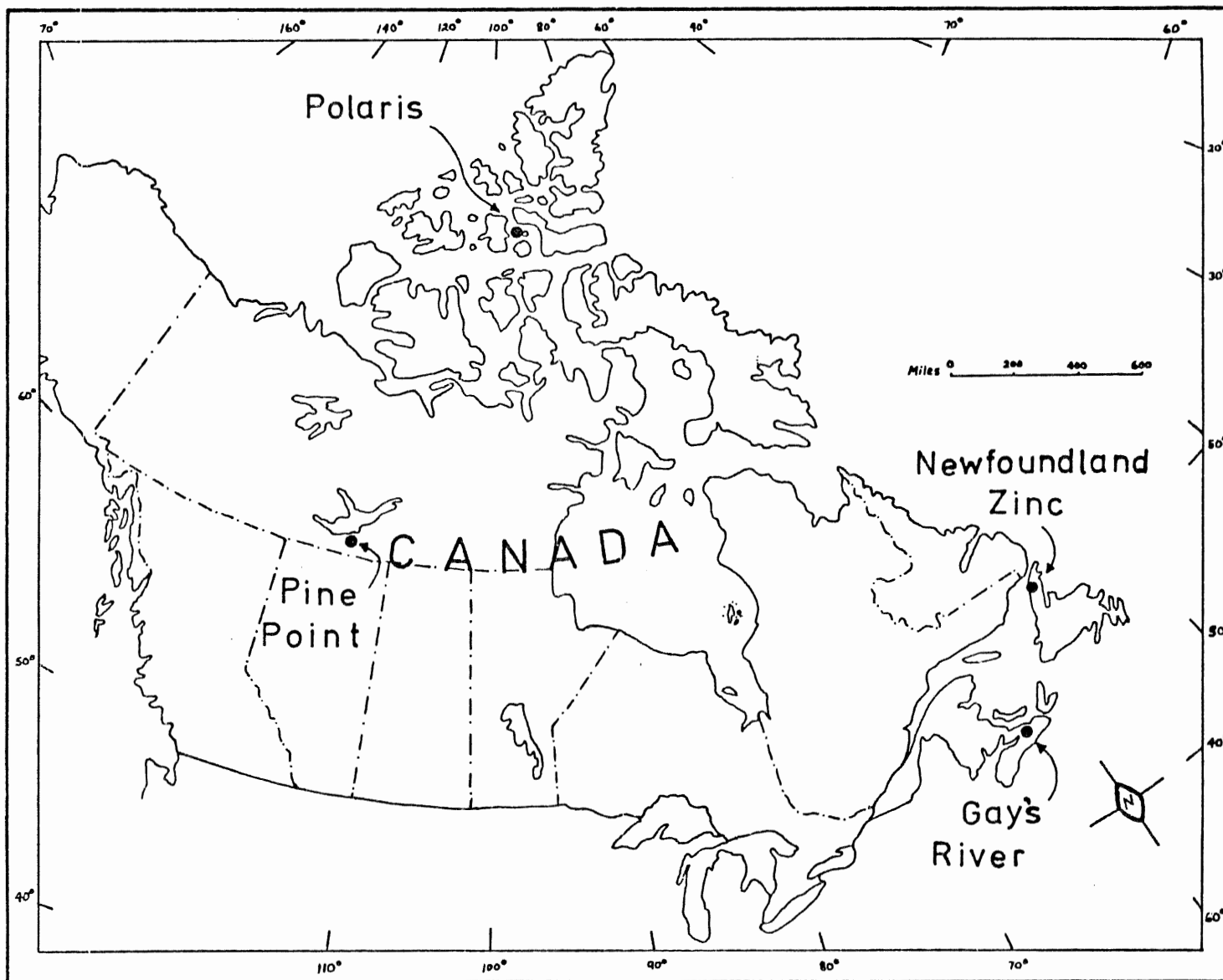


Fig. 1. Location map for the four deposits

reasons. The most compelling mover was access to samples. Large specimen suites, including both host rock and ore lithologies, for all four deposits, were in storage at the geology department of Dalhousie University in Halifax. Detailed lithologic descriptions of the specimens used in this study are given in Appendix I.

Secondly, these four areas were selected for their lack of positive association with any volcanogenic origin. For the purposes of this study, one genesis was restricted to consideration of meteoric and/or connate epigenetic brines. It is beyond the scope of this thesis to consider the complexities of uranium activity associated with volcanogenic brines.

Thirdly, they were chosen for their wide range in age (Cambrian to Mississippian) and host rock environments. This wide age and lithological variation in the examples chosen is therefore expected to provide data representative of a general nature for M.V.T.D.

#### Methods

Representative suites of 4 mineral deposits were selected. Polished thin sections were made and mineral separates were produced by hand picking, heavy liquid, and magnetic separations. Mineral identification was achieved by qualitative analysis of all mineral phases with the electron microprobe. Uranium content in the monomineralic separates was determined by the induced fission track technique. The detailed partition of uranium in coexisting mineral phases was investigated using the induced fission track mapping technique.

## 1. Induced Fission Track Technique

The principle of fission track analysis was originally developed by R. L. Fleisher, P. B. Price, and R. M. Walker in 1963. The method is reviewed in Fleisher, Price, and Walker (1969). It is currently being used by M. Zentilli, and K. Taylor of Dalhousie University, to study the occurrence of trace amounts of uranium in various ore environments. The method can detect the presence of uranium in concentrations from .001 p.p.b. up to approximately 15 p.p.m.

The various mineral phases of the four deposits were separated from the ore samples. They were purified so as no visible contamination remained. Using an agate mortar, the crystals were ground separately to a very fine powder (not sieved). The powders were then pressed into tabular pellets in a 13 mm. Perkin-Elmer anvil using a pressure 50 kp/cm<sup>2</sup> in a hydraulic press. The pellets were backed with bakelite. They were then stacked and wrapped with aluminium foil, and bound by aluminium wire. Covering each pellet was a .003 inch thick detector made of mylar plastic. Positioned regularly throughout the stack of unknowns (1 every 5) were pieces of carefully calibrated standard glass, containing 0.33 p.p.m. of homogenously distributed uranium. These standards were also covered with a plastic detector. The stacks were placed in an airtight aluminium capsule in preparation for irradiation.

Fissioning of the uranium nuclei is accomplished by bombarding the samples with slow (thermal) neutrons in a nuclear reactor. The reactor used in this study was the McMaster Nuclear Reactor at McMaster

University in Hamilton, Ontario. The neutron flux used was  $10^{14}$  neutrons/cm<sup>2</sup>/sec., integrated over four hours to  $10^{16}$  neutrons/cm<sup>2</sup>/sec. The irradiation time was four hours.

When a thermal neutron strikes the nucleus of a  $U^{235}$  or  $U^{238}$  atom, it renders that nucleus unstable. This instability results in the fission of the nucleus producing two statistically equal halves. These halves recoil in opposite directions and travel approximately 20 microns. The uranium atoms which are lying close to the surface of the pellets repel one half of the fissioned nuclei into the overlying plastic mylar detector (Fig. 2). The introduction of such a particle into a non-conducting solid such as mylar leaves a trail of radiation damaged material. This damage is the result of ionization of excited molecules, which causes the polymer chains to break. The broken ends of the chains form new chemical species, which are very reactive chemically (Fig. 3). Accordingly, each damage pit represents 1 U atom (molecule) in the rock.

These damaged areas are much too small to be seen even with the aid of a powerful microscope. They are, however, more susceptible to attack by a suitable etchant than the surrounding undamaged material. They can thereby be readily enlarged to visual proportions by etching. Excellent results were obtained by etching with 6N-NaOH, at 70°C for 20 minutes.

The detector surface containing the etched tracks was then liberally smeared with black ball point pen ink, and the excess was immediately removed. This leaves the etched pits full of black ink. This has the

effect of greatly increasing the track/background contrast and renders the tracks readily visible even at low magnification. They appear as black dots to oblique cones, depending on the angle of entrance of the fission particle into the detector.

Uranium concentrations can then be determined by visually counting the number of black spots per given area of sample detector, and equating with the number counted per equal area of standard.

Counting was conveniently achieved by viewing the detectors through a microscope using transmitted light, with a 1 cm<sup>2</sup> field of view. This field of view was produced by inserting a 1 cm square into one of the oculars of the microscope. Optimum magnification yields a suitable track size and density, usually around a power of 600x. Magnification and counting area are arbitrary but must be identical from both known and unknown. Fifty random fields were counted on each detector of the unknown samples. 100 fields were counted on each standards detector.

A simple relationship exists between the average number of tracks per area of standard, and the average per area of unknown. Using the equation:

$$\frac{U_u}{U_s} = \frac{T_u}{T_s} \quad (\text{Schroeder, Miller, Friedman, 1969})$$

U = uranium conc in p.p.m.

T = average number of tracks per field of view

u = subscript denoting unknown sample

s = subscript denoting standard

a value for the uranium concentration in each powder can be determined in parts per million, to a statistical accuracy of 10%. Haglund (1968) determined the standard deviation of the method to be 5%, while Schwarzer (1969) concluded it to be 12%. The error in this study was assumed to be within this range. The vast majority of the tracks are assumed to be the result of  $U^{235}$ , considering the  $U^{235}/U^{238}$  abundance ratio in natural systems is  $137/1$ .

The principles just discussed may also be used to accurately determine the location of the uranium in each of the mineral species, fabrics, structures, etc., by use of the fission-track mapping technique.

## 2. Induced Fission Track Mapping

To "map" the uranium concentration, a polished thin section is irradiated instead of a powdered mineral pellet. The polished thins, which are to be used, contain no cover glasses. They must also be cut into 1 cm. squares to permit packing in the standard aluminium irradiation capsules. The polished thins are covered with .003' mylar detectors and are irradiated in exactly the same manner as discussed previously. Similarly the detectors upon return from the reactor are etched and inked in the same way.

By replacing a detector in the position it occupied on the section, during irradiation, it is possible to ascertain which minerals, etc. contain uranium, how much, and where it is located in the crystals' structures. This is accomplished by viewing the detector and its thin

section through a standard transmitted light microscope, while the detector overlies the thin section.

Quantitative uranium concentrations may be computed through calibration with the standard glass' detectors as discussed earlier. Relative uranium concentrations may be achieved by comparison of fission track densities associated with the various components of the polished thin sections. In this way, the uranium content of a small portion of rock sample may be mapped (for examples, see plates 5 and 6).



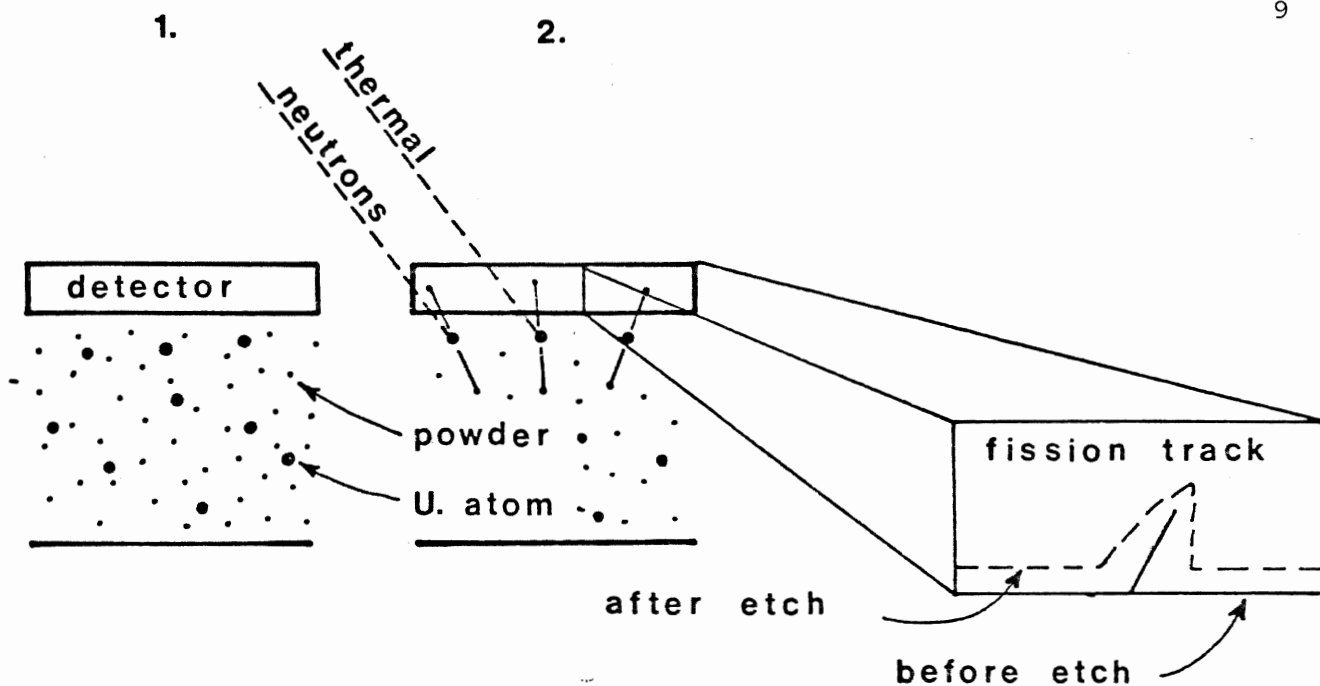


Fig. 2. Diagram illustrating the process of induced nuclear fission, and fission track production.

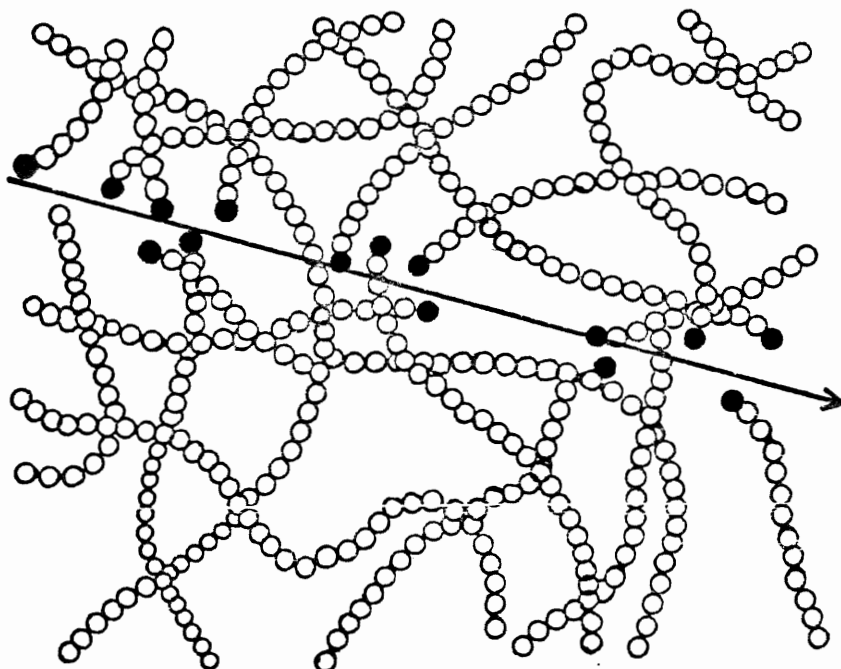


Fig. 3. In an organic polymer (mylar) the charged particle ionizes and excites molecules, breaking the chains. The chain ends form new species (black) that are highly reactive chemically. (Fleischer, Price, Walker (1969) Pg. 32)

## CHAPTER 2 - MISSISSIPPI VALLEY-TYPE DEPOSITS

M.V.T.D.'s represent one of the worlds most important sources of lead zinc ore. They occur in Canada, United States, Europe, Russia, North Africa, and Australia. One of the earliest known areas of this type of mineralization was the middle and upper region of the Mississippi River Valley in the United States. Hence, deposits displaying the characteristics of the mineralization of this area are referred to as Mississippi Valley-type Deposits.

General Characteristics of M.V.T.D.

Mineral occurrences of this type are found in a wide range of geologic time. A few small ore bodies are found in Precambrian rocks, but are relatively unimportant. The larger deposits are found in host rocks ranging in age from the Lower Paleozoic right through to the end of the Mesozoic (Stanton, 1972).

The vast majority of these deposits are hosted by relatively undeformed sedimentary carbonate rocks, which were lithified prior to mineralization. The carbonates are usually limestones (containing high Mg. calcite) and/or dolostones, which normally exhibit high permeability. This permeability may be tectonically controlled, as in collapse breccias associated with faulting or a strong joint direction. It may also be the result of dolomitization, or compaction and fracturing over a basement high. The economic mineralization is usually localized in

these areas. More often than not, these areas are paleoreefs (e.g. Pine Point, N.W.T.), but are not necessarily so. The geological conditions which tend to localize M.V.T.D. are summarized graphically in Fig. 4.

Major faults quite frequently intersect the ore bodies, and may play a significant role in their genesis. The deposits are essentially shallow in nature (<1000 feet) relative to the present base level.

A large number of the host carbonate sequences are found to lie between major sedimentary basins (Fig. 5, Nos. 7-12). These carbonates were most likely laid down on a shallow marine platform. Other host sequences are found at the edge of the platform, near the facies boundary between shallow platform carbonates and the deeper water shale environment within the basins (Fig. 5, Nos. 2, 4, 13, 14, 15).

The deposits are usually remote from possible ore forming igneous intrusions, although it has been proposed that M.V.T.D. ore bodies have formed in this manner.

The dominant mineralization is usually quite consistent. Galena, sphalerite, pyrite, and/or marcasite, barite, and fluorite are the major economic mineral species. Gangue minerals include calcite, aragonite, dolomite and sometimes siderite, ankerite and colloform silica. The lead or zinc may exist almost to the exclusion of one or the other. Barite and fluorite may be plentiful to almost absent. Chalcopyrite may exist in some deposits as a trace. The ores are usually copper and

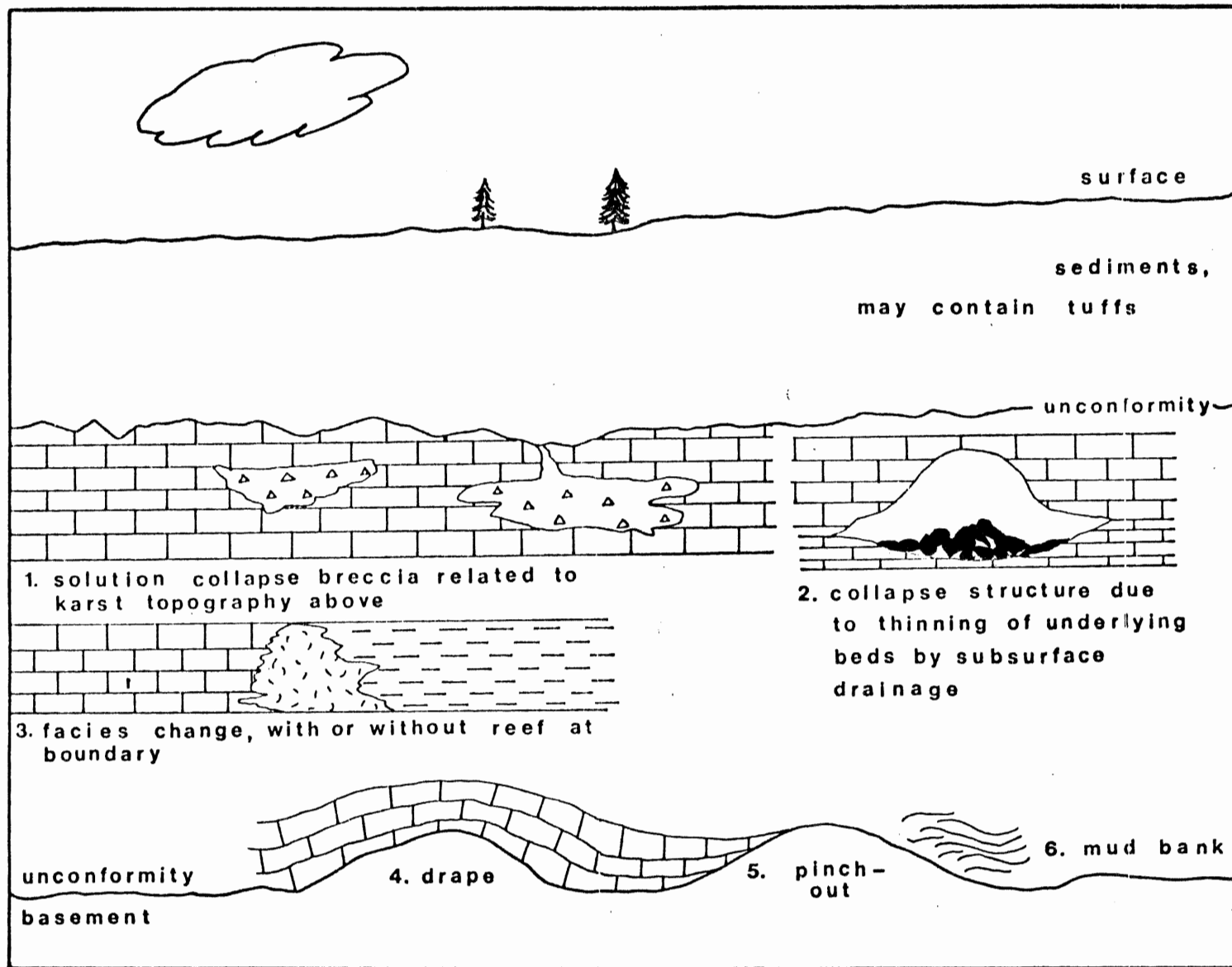


Fig. 4. Idealized vertical section illustrating features responsible for the localization of Mississippi Valley-type deposits. (redrafted from Callahan, W. H., 1967, Pg.15)

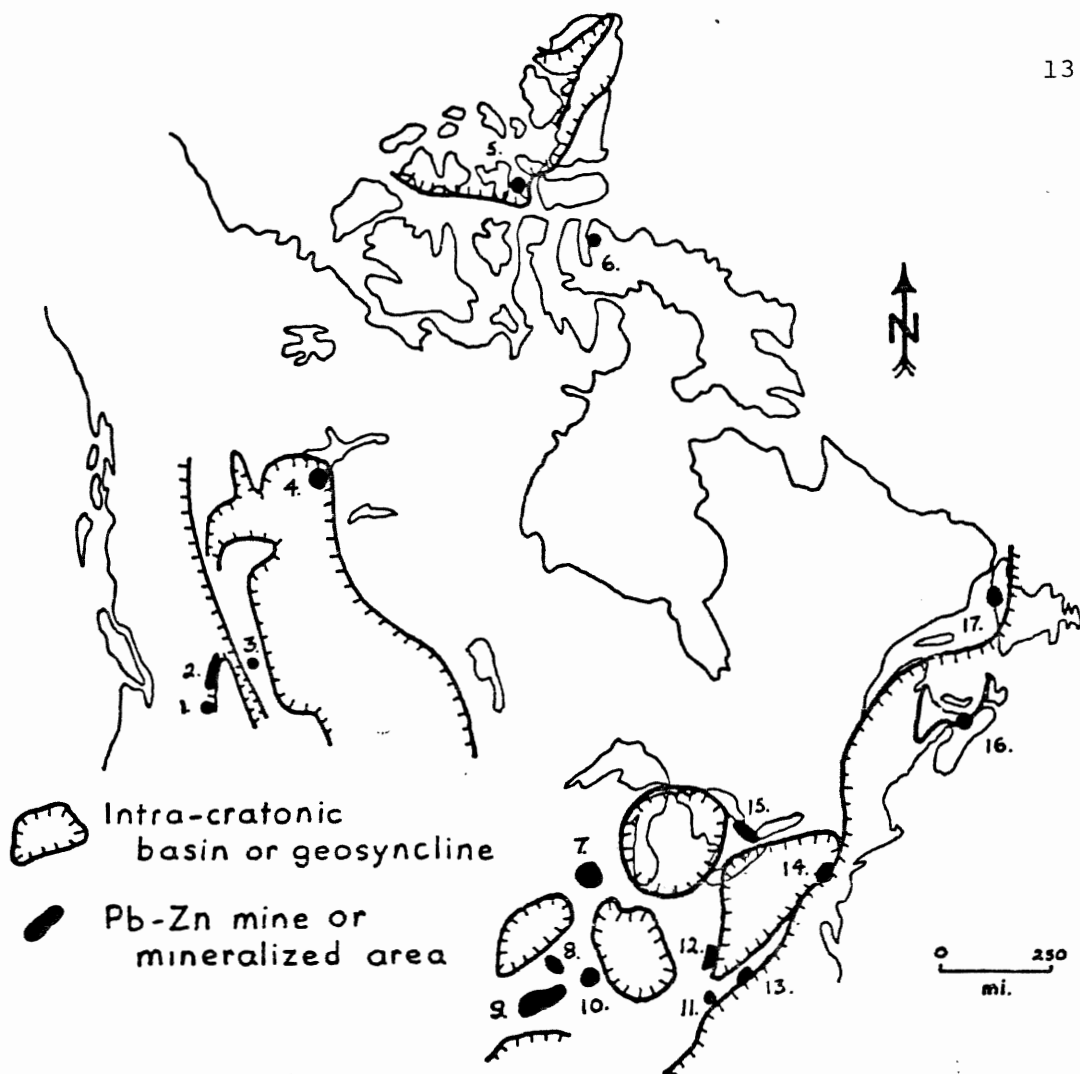


Fig. 5. Distribution of lead-zinc (-barite-fluorite) deposits in carbonate rocks relative to North American sedimentary basins. Deposits or mineral districts and age of host rocks (in parentheses) as follows: 1. Metaline area (M. Cambrian) 2. Kootenay Arc (I. Cambrian) 3. Monarch-Kicking Horse (M. Cambrian) 4. Pine Point (M. Devonian) 5. Polaris (M. Ordovician) 6. Strathcona Sound (Proterozoic) 7. Upper Mississippi Valley (M. Ordovician) 8. Central Missouri (Ordovician) 9. Tri-State (Mississippian) 10. Southeast Missouri (U. Cambrian) 11. Eastern Tennessee (L. Ordovician) 12. Central Kentucky (M. Ordovician) 13. Austinville, Virginia (L. Ordovician) 14. Friedensville, Pennsylvania (L. Ordovician) 15. Bruce Peninsula-Niagara Escarpment (M. Silurian) 16. Gay's River (Mississippian) 17. Newfoundland Zinc (I. Ordovician). (From Sangster, D. F., 1970, Pg. 28)

silver poor.

In some cases the sulfides are definitely stratiform. They may occur as well laminated beds up to tens of feet thick. More frequently, they form linings on cavity walls, small crosscutting veins, and the cementing material of breccias (collapse or otherwise) (Stanton, 1972). The textural evidence indicates that the dominant mineralization process was open space filling of the aforementioned highly permeable zones. This process is quite evident in deposits such as Pine Point and Newfoundland Zinc where large euhedral crystals line cavity walls. These crystals sometimes display impingement grain boundaries. Alternating bands of ore and host rock are common along with numerous colloform growths. These are especially well developed in the Polaris deposit, in the North West Territories. Later stage replacement of the host rock by the sulfide mineralization is also evident in some deposits. Where the ore occurs as massive bodies, the textures are usually those of a polycrystalline aggregate (Stanton, 1972). The sulfides are normally medium to coarse grained.

The dolomitization, chertification, and brecciation of the host rocks are usually well advanced or completed before mineralization begins.

The following is a brief summary of the characteristics of the

four M.V.T.D. which were analysed for this thesis. The four are Pine Point, N.W.T., Polaris, N.W.T., Newfoundland Zinc, Newfoundland, and Gay's River, Nova Scotia.

Pine Point, N. W. T.

The Pine Point deposit is situated near the south shore of Great Slave Lake, in Canada's North West Territories. It is 510 air miles north of Edmonton, and fifty miles east of the rail, air, and highway terminal of Hay River. The deposit occurs in the Great Plains physiographic province, 35 miles southwest of the margin of the Precambrian Shield (Fig. 6).

The ore zone is roughly 6 miles inland from, and 200 feet above, the level of Great Slave Lake. The area is underlain by 400 feet of Paleozoic sediments which pinch out against the Precambrian Shield to the east. There exists, in the area, a system of gentle folds and minor faults.

The host rocks are mid-Devonian carbonate sediments which display a variety of pronounced facies changes. A detailed lithologic description is published in Norris (1965). These carbonates and their associated clastics were deposited in a vast marine basin in the mid-Devonian, along the southwest flank of the Precambrian Shield.

The ore itself is hosted by a two hundred foot thick section of coarsely crystalline, clear white to buff coloured reefal dolostone known as the Presqu'ile Formation. The buff coloured dolostone appears to have been deposited as part of the reef. The white sparry dolomite seems to be the result of syn- and post-depositional recrystallization. This formation is considered by most to have been a barrier reef dividing the large basin into an open marine shaly facies to the north, and a restricted evaporitic facies to the south. The dolomitization of the reef

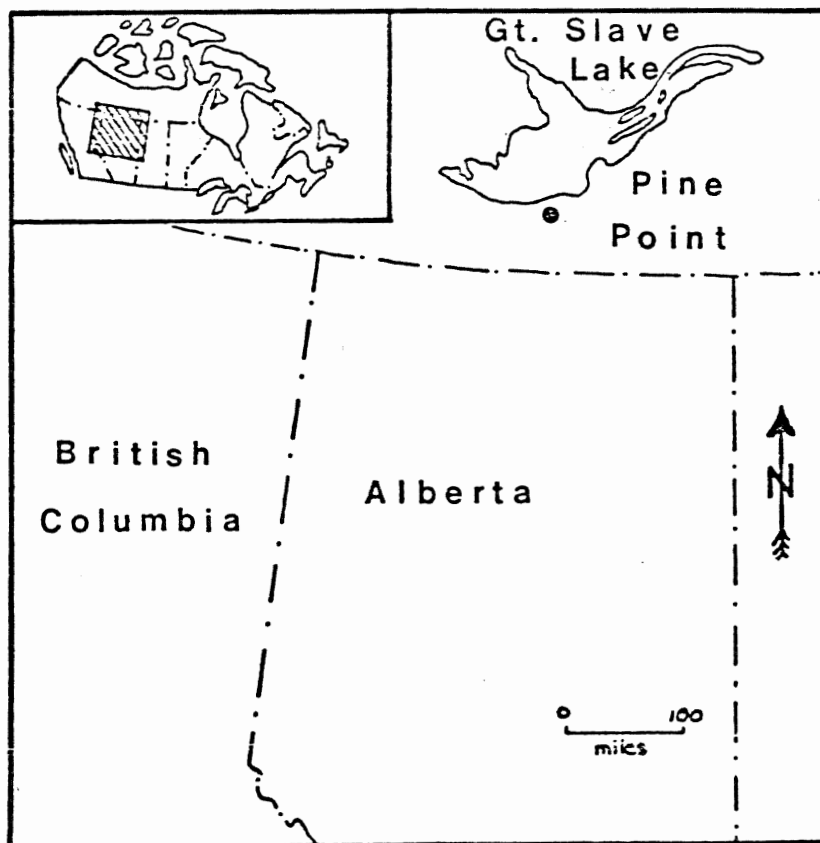


Fig. 6. Location of the Pine Point deposit (Campbell, N., 1966, Pg. 955).



is quite extensive and is generally believed to have occurred before mineralization.

The Pine Point area lies 200 miles southwest of a major fault system in the Precambrian. These faults represent the most recent structural event in Precambrian time. A few arms of these faults are sparsely mineralized with Pb-Zn. Evidence suggests that movement had ceased by the end of the Precambrian.

The metallic mineralization of the Pine Point deposit is restricted to sphalerite, galena, marcasite and pyrite in that order of abundance. Pyrrhotite and fluorite are rare. The ore bodies are restricted to a narrow zone 22 miles long. These bodies have a linear distribution within the reef and are sharply defined in lateral extent. The individual deposits range in size from a few tens of thousands to more than 3 million tons.

Sphalerite and galena replace the host dolomite in a disseminated fashion. The sulfides are also commonly deposited in vugs, joints, and cavities between breccia fragments. Areas of extensive cavity filling display cryptocrystalline sphalerite in a colloform habit. Coarse euhedral galena crystals sometimes are found growing within the sphalerite bands. The lead-zinc ratio varies from 1 to 4 to 1 to 2 (Campbell, 1966).

Traces of elemental sulfur, anhydrite, and fluid petroleum are found in and around the reef. In the ore itself, only solid pyrobitumen is found, which suggests that the petroleum present was stripped of its volatiles by the mineralizing fluids.

The most critical factors concerning the mineralization of Pine Point is the high degree of permeability and porosity developed within the reef. These factors are largely attributable to secondary solutions, causing solution collapse and porosity during dolomitization. This high degree of permeability and porosity is necessary to permit the entry of mineralizing solutions.

#### Newfoundland Zinc Mines, Daniel's Harbour, Newfoundland

The Newfoundland Zinc Mines' deposits are located on the western coast of Newfoundland, 7 miles northeast of Daniel's Harbour (Fig. 7). They are situated within a lower Paleozoic carbonate platform, which is exposed from Port Au Port Peninsula to Cape Norman (280 miles apart). The carbonate platform is underlain by Grenville Province, crystalline basement rocks.

The two major carbonate rock units found in the sequence are the St. George Formation (Cambro-Ordovician) and the Table Head Formation (Middle Ordovician).

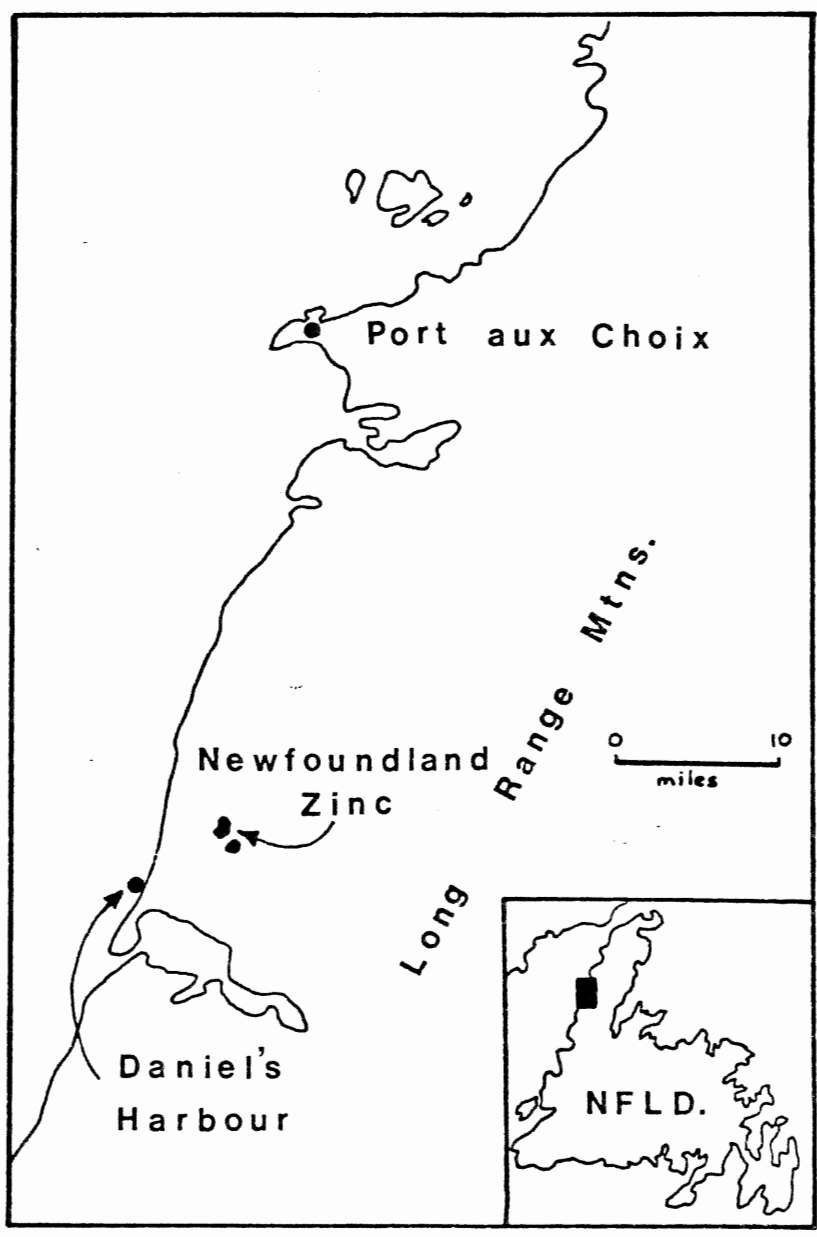


Fig. 7. Location of Newfoundland Zinc Mines  
(Collins, J. A., et al., 1973, Pg. 80)

According to Cumming (1968) the unconformable relationship between these two formations is a disconformity (the Table Head overlying the St. George).

The relevant level concerning mineralization, according to Collins,

et al. (1973) is the top 400 feet of the St. George Formation, below the unconformity. Much of the following stratigraphic description is based on his work.

The top 400 feet of the St. George Formation can be subdivided into the lower limestone host, the dark grey dolostone, and the cyclic dolostones. The lower limestone consists of interbedded limestone and fine grained dolostone. The ore host itself is a pseudobreccia which is the diagenetic result of these layers. The limestones are typically biopelaparites (fossils <5%). Preferential dolomitization of burrows gives the limestone a mottled look. The pseudobreccia appears to be the product of replacement of the limestone with very coarse pure white dolomite.

The dark grey dolostone is mainly a massive, light to dark grey pelleted dolostone.

The cyclic dolostones consist of a repeated cyclic (8 times) of conglomerate, dolostone, and bioturbites.

Recent work by T. Lane suggests the past existence of a now eroded evaporitic sequence (M. Zentilli, personal communication).

Solution collapse breccias occur as laterally discontinuous features in the lower limestone. The breccia fragments are cemented with fine grained dolomite, iron oxides, or sulfides.

The metallic mineralization of the deposit consists almost

entirely of sphalerite. Galena has been found in float only. The sphalerite is concentrated in zones parallel to a N.E. striking joint and fracture system. In these zones, the sphalerite is concentrated around the dolomite mottles. Most of the remaining voids after mineralization have since been filled with coarse white sparry dolomite. In some cases sphalerite is found filling the entire cavity as the result of a second period of mineralization.

Karstic topography and cave formation are found abundantly below the disconformity. This is the result of approximately 90+ meters of uplift prior to mineralization. The fluids responsible for the karsting probably dissolved most of the limestone leaving the dolomite mottles as surfaces for colloform sphalerite growth. The sphalerite was most likely transported in a subsurface brine.

Polaris Deposit, Little Cornwallis Island, N. W. T.

The Polaris deposit is located on the southern rim of Little Cornwallis Island in Canada's North West Territories. This island is part of Canada's Arctic Archipelago (Fig. 8). The deposit is owned by Arvik Mines Ltd., a subsidiary of Cominco Ltd. Most of the following descriptions are based on the work of E. C. Jowett (1975).

The host rocks of the Polaris deposit are included in a thick sequence which was deposited in the Franklin Geosyncline during the Ordovician and Silurian. The sequence consists mainly of evaporites, carbonates, and shales.

The Middle Ordovician Thumb Mountain Formation hosts the Polaris deposit. This unit is approximately 1700 feet thick and is composed principally of resistant grey to brown micritic limestone interbedded with medium grained buff grey porous dolostone. It is underlain by greenish argillaceous limestone and evaporite which in turn overlies 500 feet of gypsum and anhydrite. It is overlain by pyritic calcareous micritic limestone.

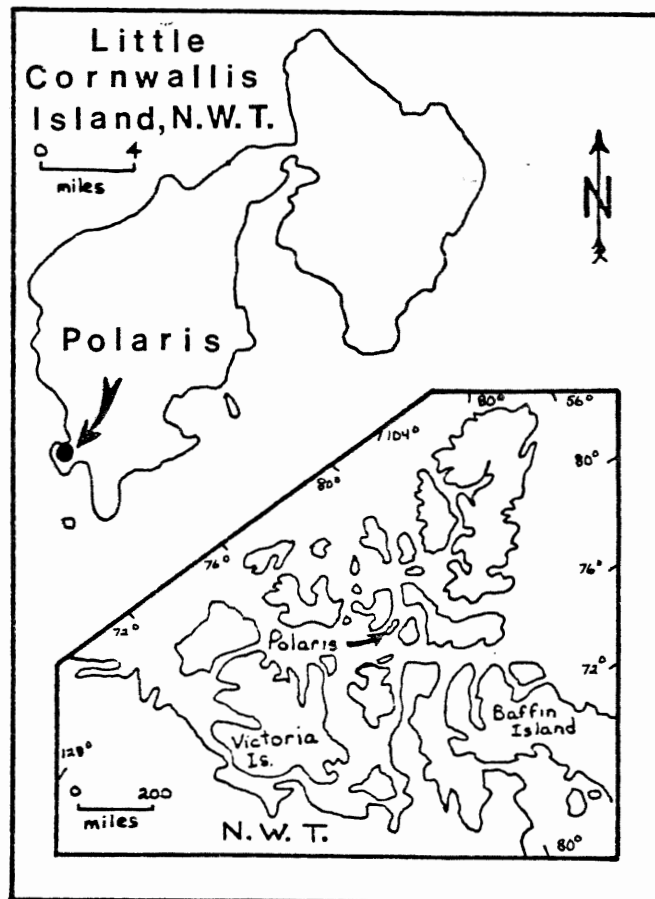


Fig. 8. Location map of the Polaris deposit, Little Cornwallis Island, N. W. T. (redrawn from Jowett, 1975, Pg. 124).

The structure in the area is quite complex. The deposit lies within the Cornwallis Fold Belt, a structural province which is characterized by normal faults and folds. These have been genetically related to the Boothia Uplift. Although some of the rocks are complexly folded and faulted, the dip of the bedding is usually quite shallow. Dolomitization is the only significant post-lithification process in the area.

The mineralization is definitely stratabound and quite irregular in shape. It consists of disseminated to massive galena, and sphalerite, with minor marcasite. The dominant mineralization process was, as at Pine Point, open space filling in vugs and cavities between fractures.

The sphalerite occurs mostly in colloform masses in the massive zone. These masses are concentric, colorbanded, microcrystalline botryoids which encrust the host rock. Roedder (1968) has suggested that these thin colourbands are the result of an annual varve phenomenon with the variety in colour reflecting the zinc content of the crystallizing medium.

Less commonly the sphalerite occurs as euhedral to subhedral, light to dark brown crystals, up to several centimeters in diameter.

Galena occurs as euhedral crystals lining the walls of and as disseminated crystals in the dolomite gangue. It also occurs in the massive zone between the sphalerite "druses" and the sparry dolomite. Large skeletal galena cubes may be filled with sphalerite bands.

Coarse grained sparry dolomite and calcite rhombs occur as gangue

minerals, infilling and lining cavity walls. Petroliferous "partings", and globules of pyrobitumen occur, sometimes coating the sparry dolomite and are thus considered to be late stage.

Barite is quite rare, and as yet no fluorite or native sulfur have been found in the Polaris area.

Jowett (1975) has proposed that the mineralizing temperature of the deposit was between 50° and 110°C with a mean of 75.5°C, from the results of fluid inclusion studies. Geological evidence indicates that the deposit formed at a depth of .5 km. or less (lithostatic pressure <150 bars.). Similarly from fluid inclusion evidence Jowett (1975) estimates that the mineralizing brines were very saline but less than 26.3% salt. The late stage dolomite and calcite crystals are assumed to have formed at less than 40 to 50°C.

#### Gay's River, Nova Scotia

The Imperial Oil owned Gay's River property is located in central Nova Scotia, five miles southeast of Shubenacadie and thirty miles northeast of Halifax (45° 02' North 63° 22' West) (Fig. 9).

The Gay's River deposit is hosted by a carbonate complex of the Middle Carboniferous (Upper Visean), Windsor Group. This host sequence is located between the Shubenacadie and Musquodoboit sub-basins which are erosional remnants of the Windsor Group within the underlying basement. The basement rocks consist of the Meguma Group, which can be



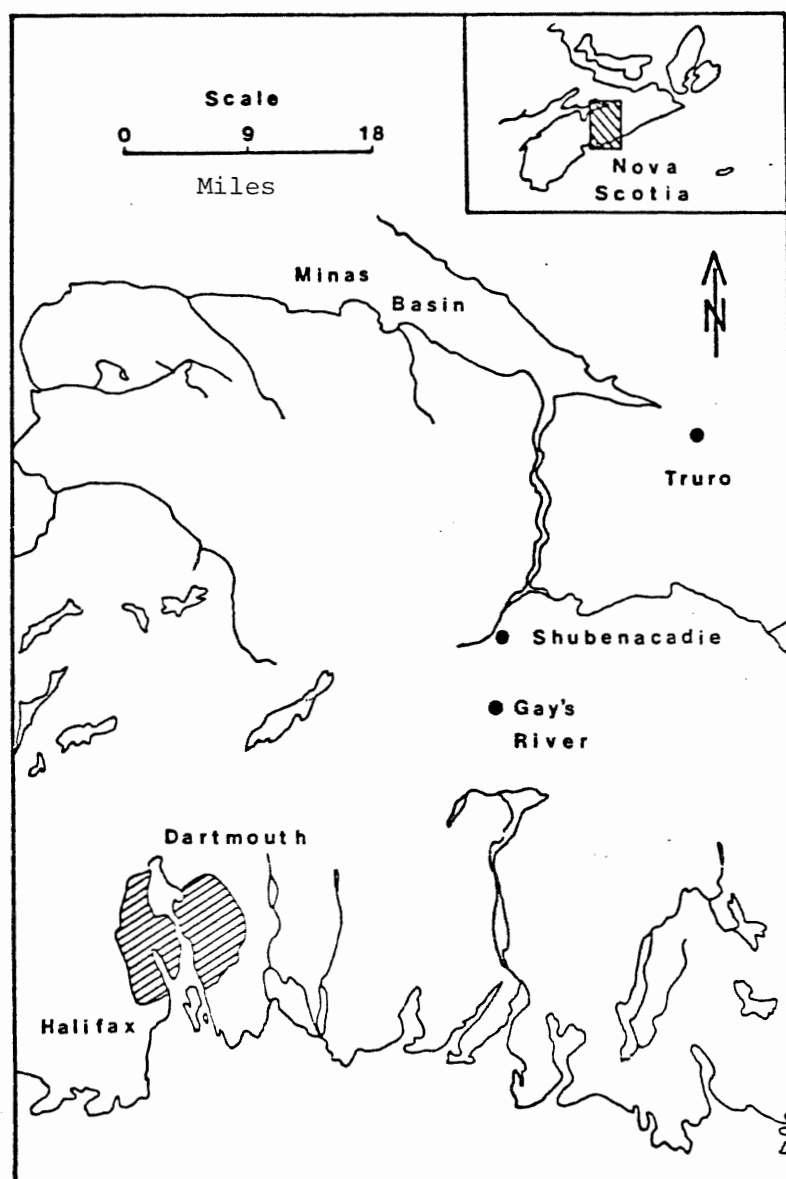


Fig. 9. Location of Gay's River deposit  
(Hartling, 1977)

subdivided into two mappable formations: the Halifax Formation consisting of black to grey slates with minor greywacke, and the Goldenville Formation which is made up of grey to green greywacke with minor black slates. The two formations are separated by a gradational contact. The Meguma Group has been extensively metamorphosed regionally. The entire Group has been tightly folded, forming long anticlines and synclines trending northeast-southwest.

The Windsor Group overlies the basement unconformably. The base of the Windsor in the Gay's River consists of a thin paraconglomerate. The clasts of this conglomerate are all Meguma quartzite and slate lithologies and vary in size from small pebbles to large tabular cobbles (up to 2 m.). They appear to be locally derived (Osborne, 1975). This conglomerate is bound by carbonate cement.

Overlying the paraconglomerate is the carbonate sequence. This sequence is composed of mostly dolomicrite, consisting of grey to buff, medium to fine grained, rhombic, micritic dolomite. In places this dolomite is very fossiliferous containing bryozoans, brachiopods, gastropods, corals, and ostracods. According to Osborne, the carbonate sequence varies from a mudstone to wackestone (Dunham Classification). He also suggests that neomorphic microspar is the only matrix type present. Numerous cavities varying in size from 2 cm. to minute interstitial voids are filled in varying stages with sparry calcite, fluorite, barite, gypsum, anhydrite, galena and/or sphalerite (Stanton 1976). Porosity is high and varies in type; including interparticle, shelter, fenestral, intraskeletal, fracture, and moldic. Carbonaceous stylolites exist throughout. Vugs left by the decay of algal structures are now filled partially or entirely by sparry calcite. Non skeletal grains are found throughout including faecal pellets, peloids, and oolites. MacLeod (1975) indicates that the carbonate sequence has been extensively dolomitized.

Overlying the carbonate sequence, and subsequently flanking the deposit is a thick evaporite unit. The evaporites consist of a rim of

gypsum surrounding a core of anhydrite which is locally rich in halite. The entire section is overlain by glacial till averaging 40 metres in thickness. The carbonate complex itself is for the most part undeformed.

The mineralization is dominantly galena and sphalerite. These occur in the dolomicrite along with minor amounts of chalcopyrite, marcasite, barite, fluorite and sparry calcite gangue. The lead zinc ratio varies from 1:1 to 1:2 (MacLeod, 1975).

The honey-yellow sphalerite is found in fine grained aggregates, veinlets, stringers, and irregular masses up to 5 mm. across. Galena occurs in the same manner, but also fills the internal pore spaces of some of the skeletal grains. Euhedral to subhedral cubes attach themselves to the walls of both vugs and veins. Both sphalerite and galena exhibit open space filling and host rock replacement (Stanton, 1976). Stanton recognizes a paragenetic sequence of marcasite, chalcopyrite, sphalerite and galena. Zoning of the mineralization indicates marcasite and chalcopyrite are restricted to the very base of the carbonates. Sphalerite dominates galena at shallow depths whereas the role is reversed with increasing depth.

The section records a single transgressive episode of the Windsor sea onto the Meguma paleoheadland. Osborne indicates that the transgression was rapid, followed by shoaling upward growth of the carbonate "mud bank". The basal conglomerate represents a paleo talus slope occupying the paleo headland. Most authors tend to agree that the mud mound

represents shallow water, low energy deposition on a prograding tidal flat (Osborne, 1977; MacLeod, 1975; Hartling, 1977).

CHAPTER 3 - BEHAVIOUR OF URANIUM IN THE CARBONATE ENVIRONMENT  
THEORETICAL CONSIDERATIONS, AND PREVIOUS WORK

Although the behaviour of uranium in the carbonate environment has been extensively studied, there exists a limited amount of published material on the subject. This is probably due to the lack of an appreciable number of economic deposits of this variety, although a few do exist (e.g. Grants, New Mexico; Tyuya-Muyun Uzbek, U.S.S.R.). Previous authors include Bell (1955, 1960, 1963), Haglund, et al. (1969), Gvirtzman, et al. (1973), Tatsumoto, et al. (1959), Gabelman (1956), Baranov (1956), and Schroeder, et al. (1970):-

Carbonates are among the least uraniferous rocks in the earth's crust, usually containing between 0 and 4 p.p.m. of syndeformed uranium. Table I summarizes the "normal" uranium content of various carbonate minerals and rock types. Carbonates are usually deposited in slightly oxidizing conditions (some in very slightly reducing) in the marine environment. Uranium in its oxidized state ( $(U^{+6}O_2)^{2+}$  uranyl ion) forms very soluble complexes with the most abundant ionic species in marine water:  $CO_3^-$ ,  $SO_4^{=}$  and  $Cl^-$  under a wide variety of pH (<3->10). Consequently, the solubility of uranium in oxidizing solutions is greatly increased by an increase of these species. The carbonate complexing is enhanced by a high pH as the carbonate dissociation is shifted towards formation of  $CO$  ion at the expense of  $H_2CO_3$  and  $HCO_3^-$ . In its reduced state ( $U^{+4}$  uranous ion) uranium forms the same complexes under slightly reducing conditions and thus remains soluble. Under strongly reducing conditions uranium may be precipitated as uraninite ( $U^{+4}O_2$ ), thorianite ( $(Th,U)O_2$ )

or coffinite ( $U(SiO_4) \cdot (OH)_4$ ) (Fig. 9). Rarely are such strongly reducing conditions realized in the open or restricted marine environment. If they are, it is usually the result of the decay of organic matter. Therefore it seems highly unlikely that uranium minerals would be deposited syngenetically with pure carbonate rocks. Therefore any syngenetic uranium deposited in most carbonates must be associated with impurities (Bell, 1963). The various impurities which may contain uranium in the carbonate environment are heavy mineral detritus, marine apatite, fluorite

Table 1. Uranium Content of Various Carbonate Rock Types

ROCK TYPE	URANIUM CONTENT (in p.p.m.)	REFERENCE
Red Sea and Bermuda Corals	2.5 - 3	Gvirtzman ( <u>et al.</u> ) (1973)
Marine Aragonite	Several	Tatsumoto, <u>et al.</u> (1959)
Oolites	0.x - 0.0x	Tatsumoto, <u>et al.</u> (1959)
Various Carb.	0.01 - 4.0	Bell (1963)
Rock Types		
Dolostones	.7 - 3.8	Bell (1956)
Soviet Limestones	1.2 - 5.4	Baranov (1956)
Anhydrite	.0001 - .0002	Bell (1960)
Dolomite	.000x - .00x	Bell (1960)
Corals	1.6 - 5.8	Schroeder, <u>et al.</u> (1970)
Ocean Water	.002	McKelvey, <u>et al.</u> (1955)
Mississippi Limestone	1.02 - 1.11	Tatsumoto, <u>et al.</u> (1959)
Aragonite	2.7 - 4.7	Gvirtzman, <u>et al.</u> (1973)
High Mg Calcite	2.0 - 3.3	Gvirtzman, <u>et al.</u> (1973)

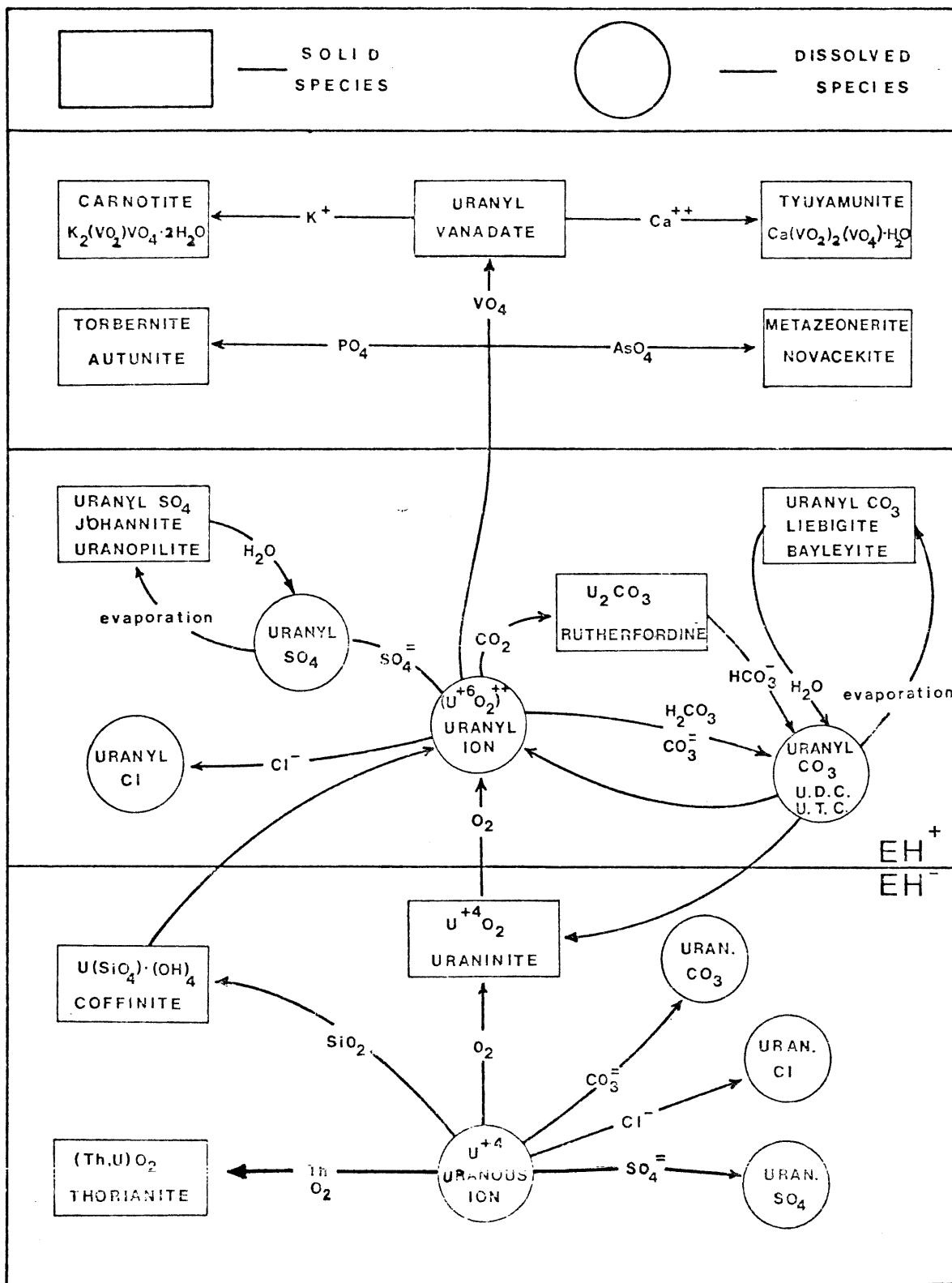


Fig. 10. Flow Chart of the Major Aspects of Uranium Geochemistry.

and detrital organic matter. The heavy minerals which are most likely to contain uranium are igneous apatite, fluorite, sphene, and monozite.

Marine apatite is considered to be the most efficient concentrator of syngenetically deposited uranium in most types of carbonate rocks. It is a common constituent of carbonate sediments, and its uranium content usually ranges from .005 to 0.02 per cent. Uranium substitutes for calcium atoms in the phosphate lattice. The  $U^{+4}$  ion has an ionic radius of  $0.97 \text{ \AA}$  (V.E. McKelvey, et al.) while the calcium ion has a radius of  $0.99 \text{ \AA}$ . The high abundance of Ca plus the similarity in size probably accounts for this tendency to substitute. The absence of uranium substitution for Ca in minerals such as anorthite, calcite, and gypsum is probably the result of the charge difference (McKelvey, et al. 1955).

The substitution of uranium atoms for Ca atoms also explains why small amounts of uranium are found in some fluorites.

Uranium also is deposited syngenetically with sediments by adsorption onto the surfaces of clay particles. Similarly uranium forms organo-uranium compounds quite readily, with any available type of organic material (decaying detritus, decaying plant or animal matter, etc.) and thus is found incorporated in dark organic rich sediments (e.g. black shales).

The concentration of uranium in evaporites is usually quite low. The enrichment of  $CO_3^{=}$  ion in the evaporite brines tends to render the uranium soluble until the last fluids are evaporated. Once deposited



by evaporation, any uranium would be very susceptible to erosion by wind, or redissolution if the area was reinvaded by fluids.

Epigenetic uranium mineralization is known to occur in carbonate host rocks. Table 2 summarizes these occurrences. The uranium is usually supplied to the ore environment in the oxidized state, be it in magmatic hydrothermal solutions, sweet meteoric groundwaters, or dense saline brines. Deposition is caused by cooling (as in hydrothermal vein deposits), evaporation (as in efflorescent and calcrete deposits), and reduction (as in peneconcordant deposits). The reducing agents are usually organic matter and associated products ( $H_2S$ ,  $S^{2-}$ ,  $H_2$ , coal, humates); but reduction of uranium may also occur during oxidation of  $FeS_2$ . The processes of reduction and its effects on ore formation will be dealt with further in the discussions.

Table 2. Types of Epigenetic Uranium Deposits in Carbonates

MINERALIZATION TYPE	MINERALS	EXAMPLES
1) hydrothermal solutions from an igneous source (deposited by cooling)	carnotite tyuyamunite	Tyuya-Muyun, U.S.S.R. Shrinkolobwe, Rep., of Congo
2) efflorescent deposits coating cave walls (deposited by evaporation)	carnotite, urophane bayleyite, tyuyamunite schroeckingerite	Tyuya-Muyun, U.S.S.R. Pryor Mtns., U.S.A.
3) peneconcordant deposits in fetid limestones (deposited by reduction)	uraninite, carnotite, urophane, tyuyamunite	Grants, N.M., U.S.A. Sundance Wy., U.S.A.
4) interstitial as calcrete in clastic sediments (deposited by evaporation)	carnotite	Yeelirrie Dist., Australia

## CHAPTER 4 - RESULTS

The uranium concentrations of the four selected deposits varied from .001 p.p.m. in several sulfide minerals to 8.43 p.p.m. in a small vein of sparry calcite from Pine Point. The results have been summarized in Tables 3 to 11 inclusive, according to mineral type.

Table 3  
Concentrations in p.p.m. of Uranium in Galena

MEAN	RANGE	# OF SPEC.	LOCALITY
0.009 ( $\sigma$ -0.015)	.001-.001-.002 .002-.002-.002 .003-.011-.011 .05	10	Polaris Deposit, N.W.T.
0.104 ( $\sigma$ -0.145)	.001-.206	2	Gay's River, Nova Scotia
0.006 ( $\sigma$ -0.002)	.004-.007-.007	3	Pine Point, N.W.T.
$\bar{X}$ 0.04			

Table 4  
Concentrations in p.p.m. of Uranium in Sphalerite

MEAN	RANGE	# OF SPEC.	LOCALITY
0.012 ( $\sigma$ -.009)	.001-.001-.007 .007-.008-.01 .014-.018-.023 .027	10	Polaris Deposit, N.W.T.
0.07 ( $\sigma$ -.120)	.002-.005-.023 .25	4	Gay's River, Nova Scotia
0.005 ( $\sigma$ -0.004)	.001-.006-.008	3	Pine Point, N.W.T.
0.049 ( $\sigma$ -0.027)	.068-.03	2	Newfoundland Zinc Newfoundland
$\bar{x}$ 0.03			

Table 5  
Concentration in p.p.m. of Uranium in Marcasite

MEAN	RANGE	# OF SPEC.	LOCALITY
0.063	.04-.04-.07 .10	4	Polaris Deposit, N.W.T.

Table 6

Concentrations in p.p.m. of Uranium in Sparry Dolomite and Calcite

MEAN	RANGE	# OF SPEC.	LOCALITY
3.238 ( $\sigma$ -0.189)	3.059-3.221-3.435 (dolomite)	3	Polaris Deposit, N.W.T.
0.008 ( $\sigma$ -0.007)	.001-.004-.011 .017 (calcite)	4	Gay's River, Nova Scotia
0.337 ( $\sigma$ -0.325)	.011-.012-.067 .191-.196-.244- .460-.472-.749 .968 (dolomite)	10	Pine Point, N.W.T.
8.43	8.43 (calcite)	1	Pine Point, N.W.T.
0.141 ( $\sigma$ -0.155)	.002-.025-.080 .121-.191-.424 (dolomite)	6	Newfoundland Zinc Newfoundland
$\bar{X}$ 3.003			

Table 7

Concentrations in p.p.m. of Uranium in Fluorite

MEAN	RANGE	# OF SPEC.	LOCALITY
0.952 ( $\sigma$ -1.592)	.003-.064-2.79	3	Gay's River, Nova Scotia

Table 8  
Concentrations in p.p.m. of Uranium in Pyro-bitumen

MEAN	RANGE	# OF SPEC.	LOCALITY
0.218 ( $\sigma$ -0.218)	.064-.372	2	Gay's River, Nova Scotia
1.205		1	Newfoundland Zinc Newfoundland
$\bar{x}$ 0.712			

Table 9  
Concentrations in p.p.m. of Uranium in Dolostone Host Rocks

MEAN	RANGE	# OF SPEC.	LOCALITY
1.011 ( $\sigma$ -0.616)	.30-1.347-1.385	3	Polaris Deposit, N.W.T. (Thumb Mtn. Fm.)
1.379 ( $\sigma$ -0.239)	.873-1.121-1.35	4	Gay's River Nova Scotia (Windsor Gp, A Zone)
1.969 ( $\sigma$ -0.329)	1.59-2.146-2.171	3	Pine Point, N.W.T. (Presqu'ile Fm.)
0.46 ( $\sigma$ -0.05)	.424-.495	2	Newfoundland Zinc (St. George Fm.)
$\bar{X}$ 0.977			

Table 10  
Concentrations in p.p.m. of Uranium in Inclusions

MEAN	# OF SPEC.	LOCATION & DESCRIPTION
5.56	5	quartz grains found in host dolostone at Gay's River, N. S.
3.14	2	slate chips found in host dolostone at Gay's River, N. S.
0.025	1	biotite grains in host rock of Pine Point, N.W.T.
1.266	numerous	indistinguishable inclusions in sphalerite ore, Newfoundland Zinc
1.73	1	intraclast of sphalerite, galena and dolomite in host rock of Pine Point, N.W.T.
$\bar{X}$ 2.344		

Table 11  
Concentration of Uranium in p.p.m. in Skeletal Grains

MEAN	# OF SPEC.	LOCATION & DESCRIPTION
1.87	1	unidentified brach valve in host bioclastic dolostones of Gay's River, N. S.

PINE POINT	$\bar{X}$	0.006	0.005		1.311			0.878	1.969
	RANGE	0.004 -	0.001 -		0.011 -			0.25 -	1.59 -
POLARIS	$\bar{X}$	0.009	0.012	0.063	3.238				1.011
	RANGE	0.001 -	0.001 -	0.04 -	3.054 -			0.30 -	1.385
NFLD. ZINC	$\bar{X}$		0.035		0.141		1.205	1.266	0.46
	RANGE		0.068 -		0.002 -				0.424 -
GAY'S RIVER	$\bar{X}$	0.104	0.07		0.008	.952	0.218	4.35	1.379
	RANGE	0.001 -	0.002 -		0.001 -	0.003 -	0.64 -	3.14 -	0.873 -
		0.206	0.25		0.017	2.79	3.72	5.56	2.17
values in p.p.m.		GALENA	SPHALERITE	MARCASITE	CARBONATE	FLUORITE	ORGANICS	INCLUSIONS	HOST ROCK

Table 12. Uranium Content of the Various Mineral Species found in the Four Deposits.

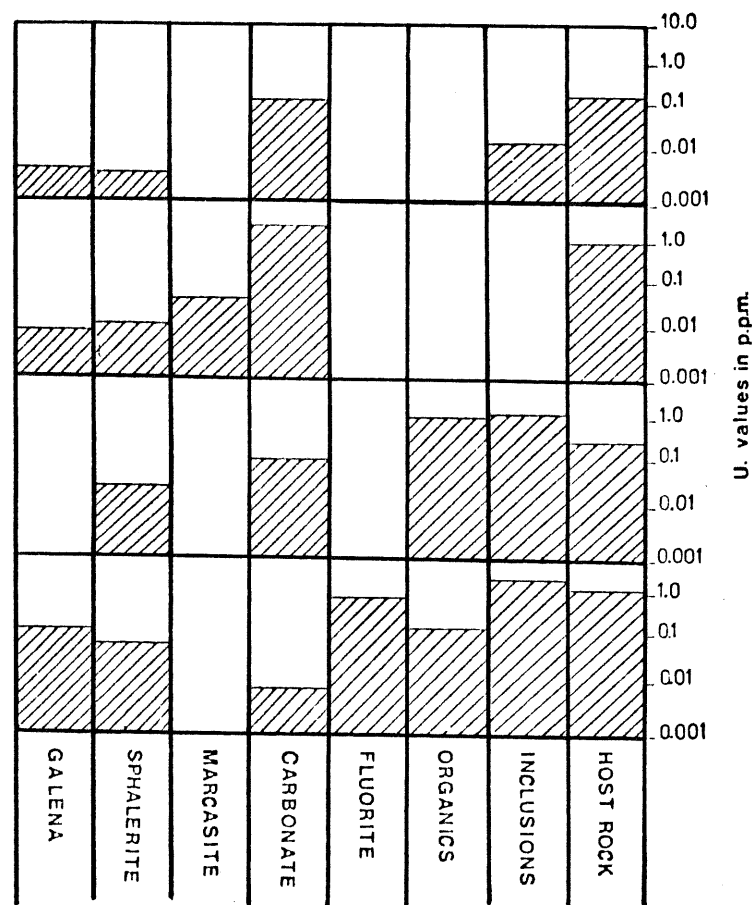


Fig. 11. Histograms displaying uranium content of the mineral species shown in Table 12.

## PLATES

Photographic plates of representative coexisting mineral phases obtained from the polished thin sections are presented on the following pages. These plates are intended to display various uranium concentrations which were studied using the induced fission track mapping procedure. The majority of these photographs are in pairs, one displaying the area of interest as observed in the polished thin section, and the other showing the fission track distribution of the same region.

The very finely banded colloform sphalerite which was commonly observed in the ore specimens of the Polaris deposit is presented in plates 1 and 2.

The uranium distribution of a brachiopod valve found in the host dolostone of the Gay's River deposit is shown in plates 3 and 4.

A representative calcite vein cutting the host dolostone of the Pine Point deposit is displayed with its uranium distribution in plates 5, 6, and 8.

The colloform banding of sphalerite around dolomite mottles in the Newfoundland Zinc Mines is shown in plate 7. Although not as fine grained as the banding observed in the Polaris Mine, the principle is the same.

The enrichment of uranium along the contact between a zone of massive galena, and a zone of sparry calcite in the Pine Point deposit is



the subject of plates 9, 10, 15, and 16.

A zone of calcite which is found infilling between sphalerite bands in the Newfoundland Zinc deposit is shown in plates 11 and 12. This zone displays a uranium enrichment of 8x over the surrounding calcite crystals.

A slate inclusion and brachiopod valve set in the host dolostone in the Gay's River deposit are displayed in plate 13. The uranium concentrations of these grains, as well as those of the host dolostone and sparry calcite are shown in plate 14. Similarly the uranium content of the galena in the Gay's River deposit is presented in plates 17 and 18.

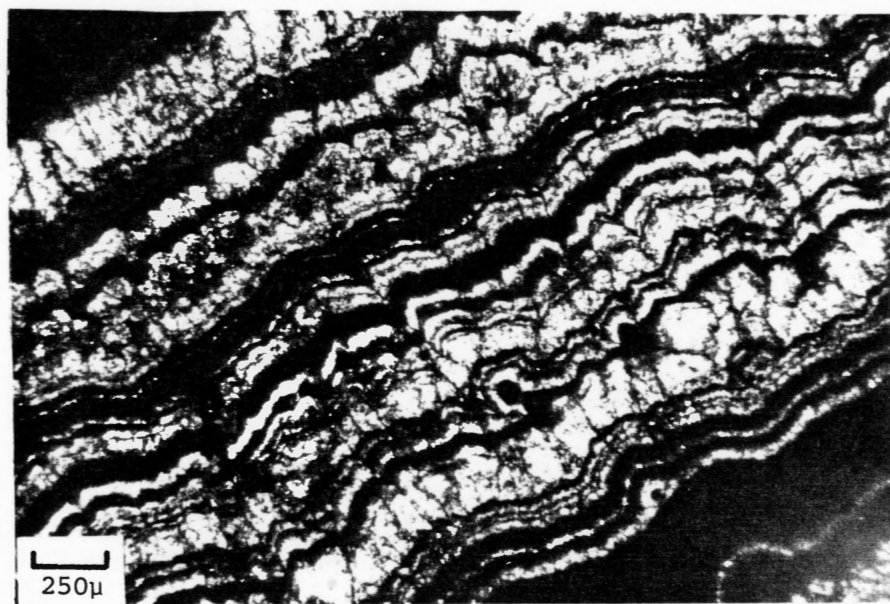


Plate 1. Close up of finely banded colloform sphalerite -  
Polaris Deposit (.01 p.p.m. U)

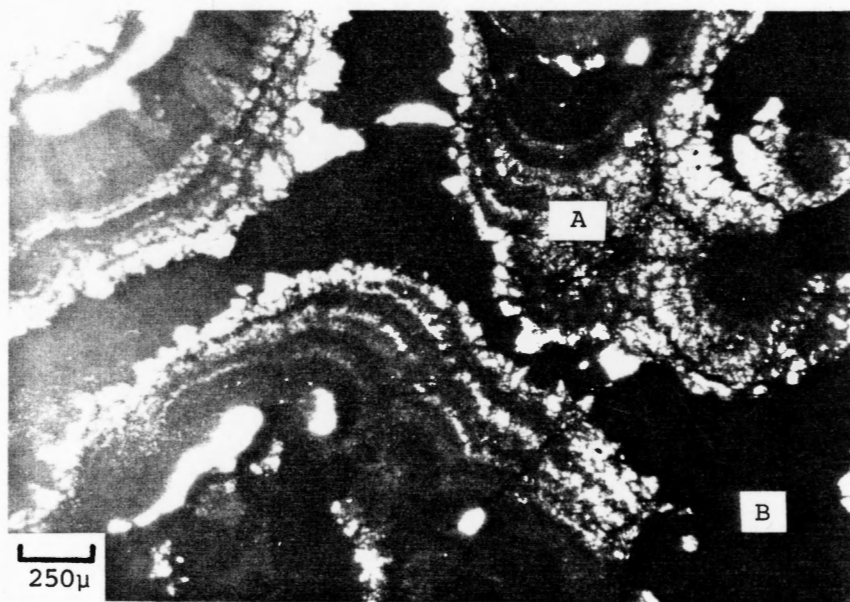


Plate 2. Close up small botryoids of sphalerite (A)  
with interstitial galena (B) - Polaris  
Deposit (A) (.007 p.p.m. U) (B) (.002 p.p.m. U)

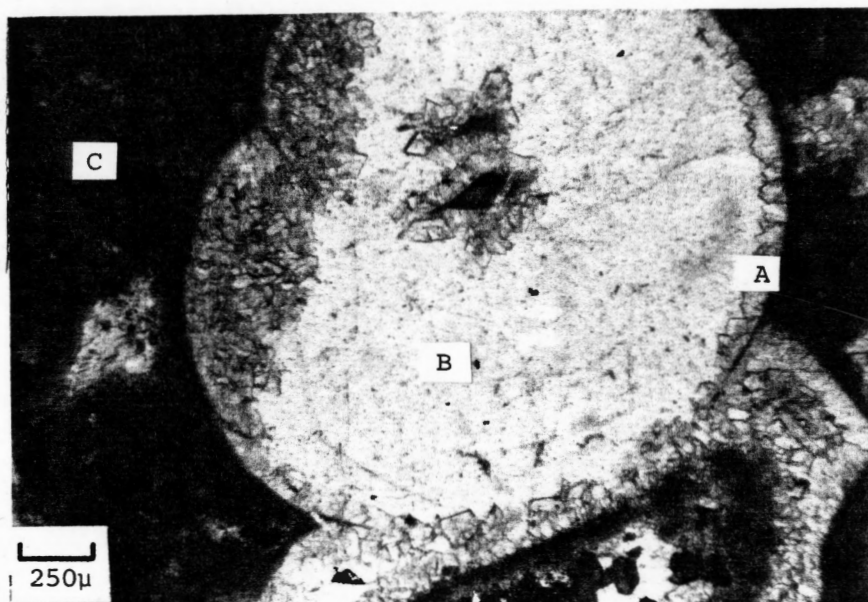


Plate 3. Brachiopod valve lined with 1st generation dolomite (A) and filled with 2nd generation calcite (B), surrounded by host dolostone (C) - Gay's River  
 (A) 1.65 p.p.m. U (B) .001 p.p.m. U (C) 1.35 p.p.m. U



Plate 4. Fission track dolostone of the same view as Plate 3 - Gay's River

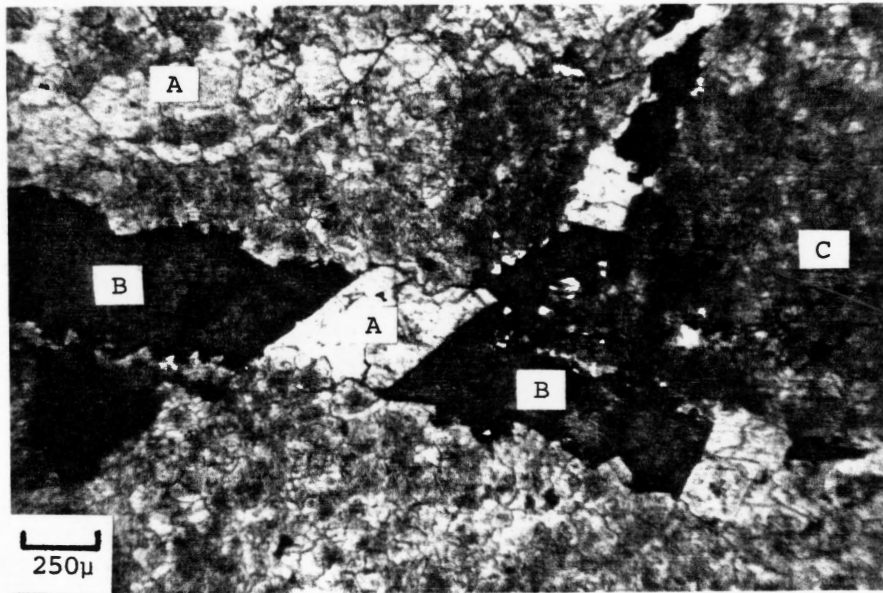


Plate 5. Veins of calcite (A) containing large crystals of sphalerite (B) surrounded by the host dolostone (C) - Pine Point  
 (A) 8.43 p.p.m. (B) .001 p.p.m. (C) 1.59 p.p.m.

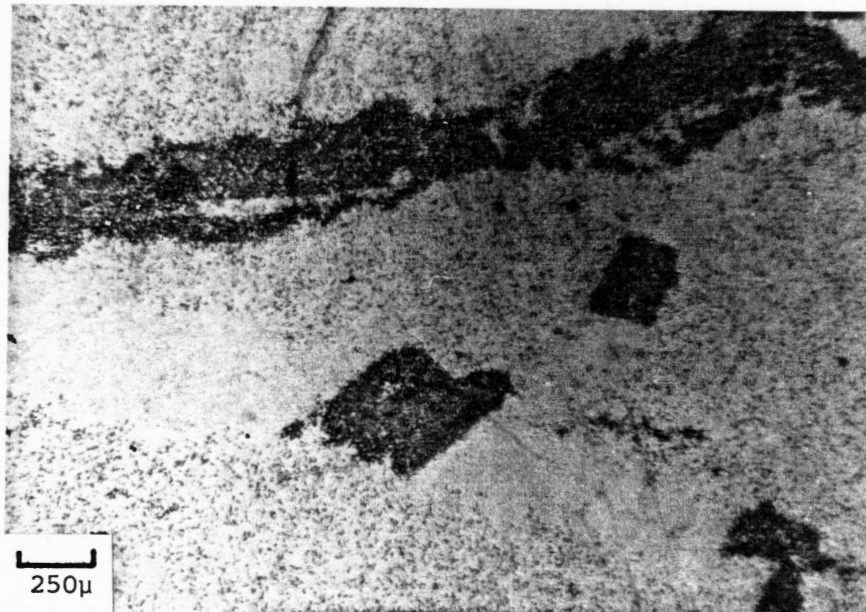


Plate 6. Fission track distribution of the same view as in Plate 5 - Pine Point

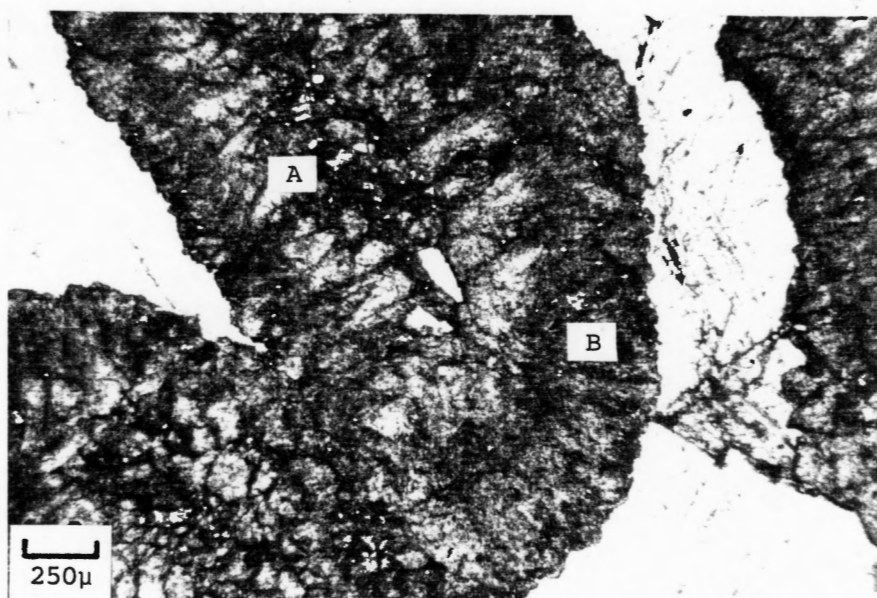


Plate 7. Coarse grained light grey sphalerite (A) coated with fine grained light brown sphalerite (B). The voids are filled with dolomite - Newfoundland Zinc  
 (A) .95 p.p.m. U (B) .08 p.p.m. U

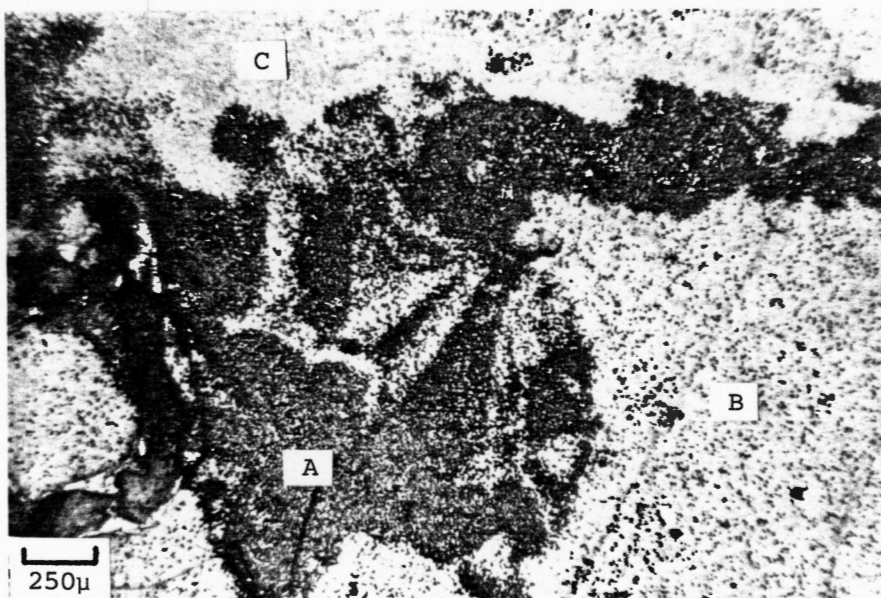


Plate 8. Close up view of the track distribution of the calcite vein in Plate 5. Areas of track concentration (A) are over calcite, while lesser density is over dolostone (B). Areas of no tracks are over sphalerite (C) - Newfoundland Zinc

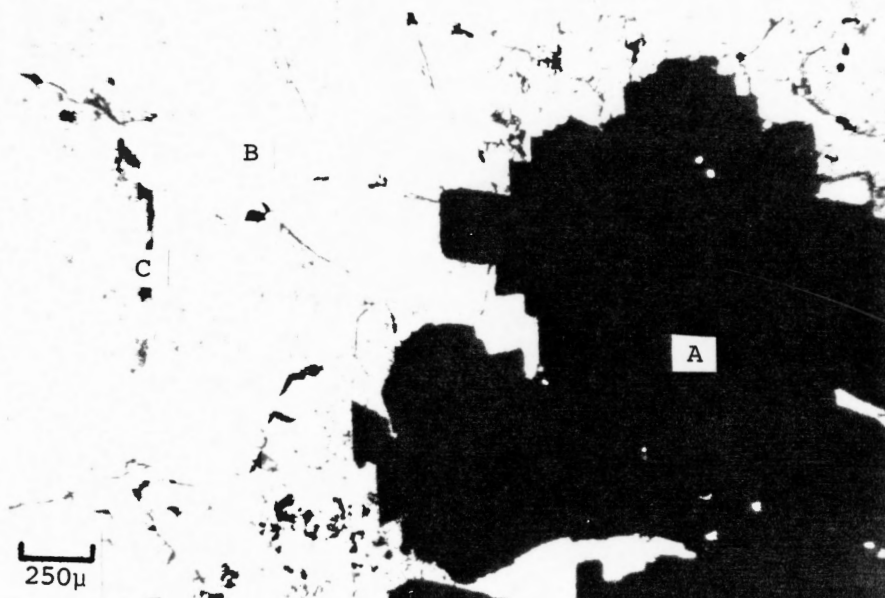


Plate 9. Coarse grained massive galena (A) in contact with calcite (B) containing styolites (C) - Pine Point  
 (A) .004 p.p.m. U (B) 0.749 p.p.m. U (C) 0.75 p.p.m. U

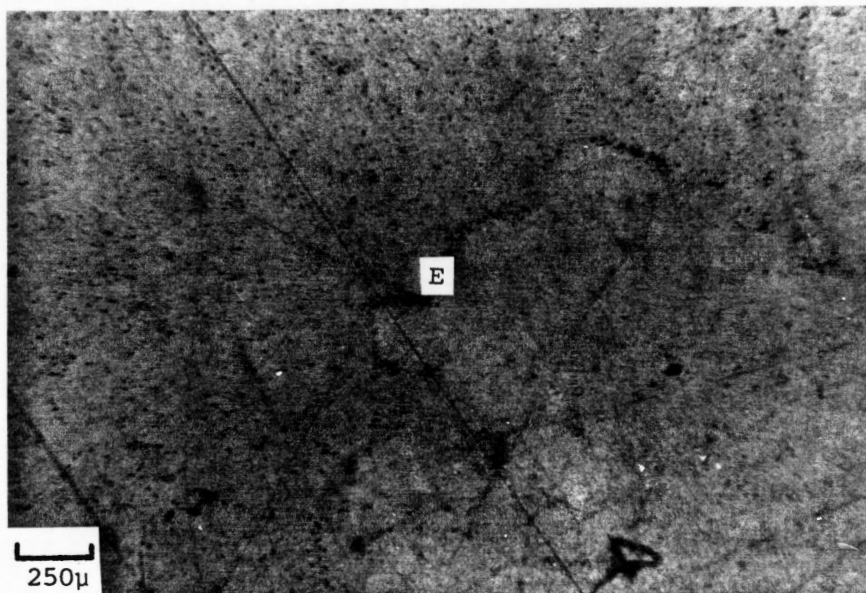


Plate 10. Uranium distribution in Plate 9 showing the concentration along the contact between the galena and calcite - Pine Point. contact (E) contains 2.32 p.p.m. U

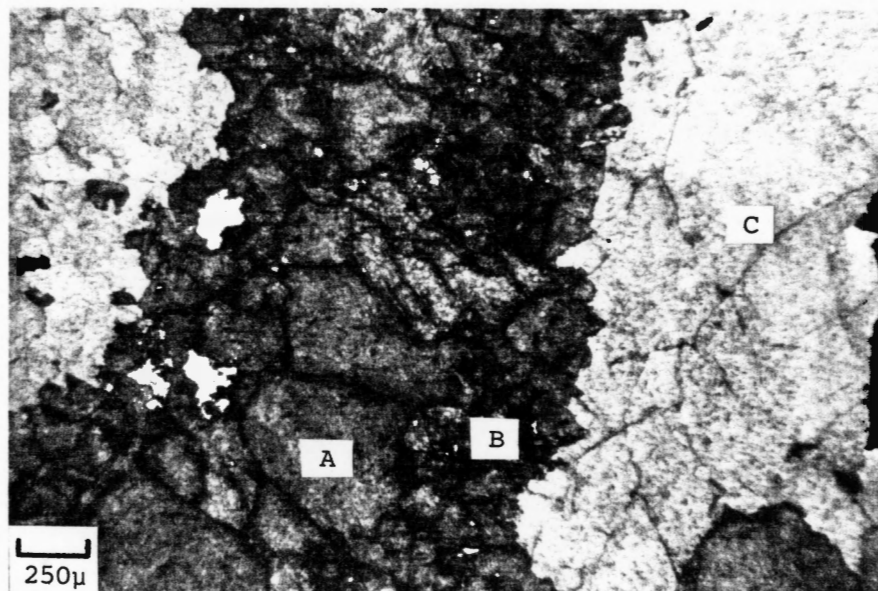


Plate 11. Coarse grained sphalerite (A) coated by fine grained sphalerite (B). Calcite (C) is found infilling between the sphalerite bands - Newfoundland Zinc (A) .86 p.p.m. U (B) .007 p.p.m. U

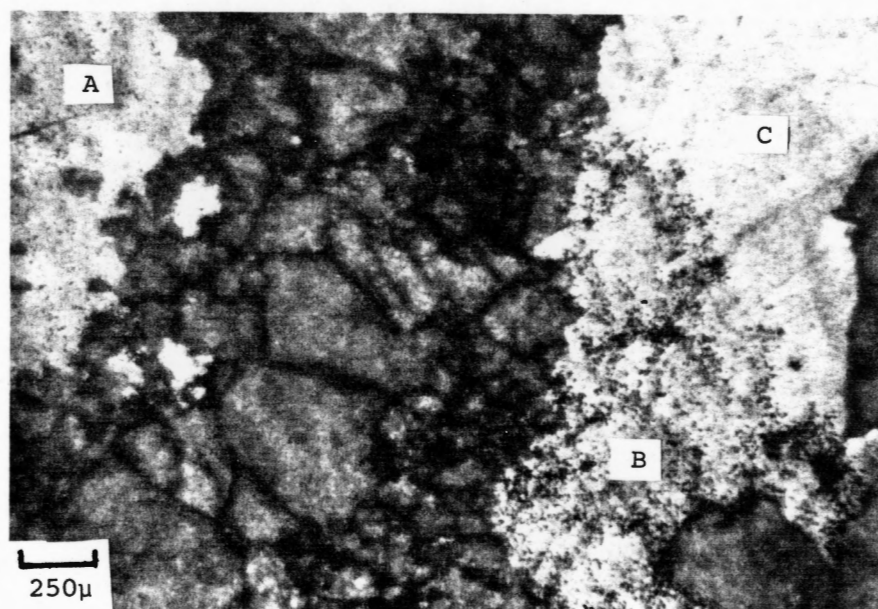


Plate 12. Overlay of the detector showing track distribution of area in Plate 11. Note the three different concentrations in the calcite (A), (B) and (C) - Newfoundland Zinc (A) .424 p.p.m. U (B) 3.336 p.p.m. U (C) .022 p.p.m. U

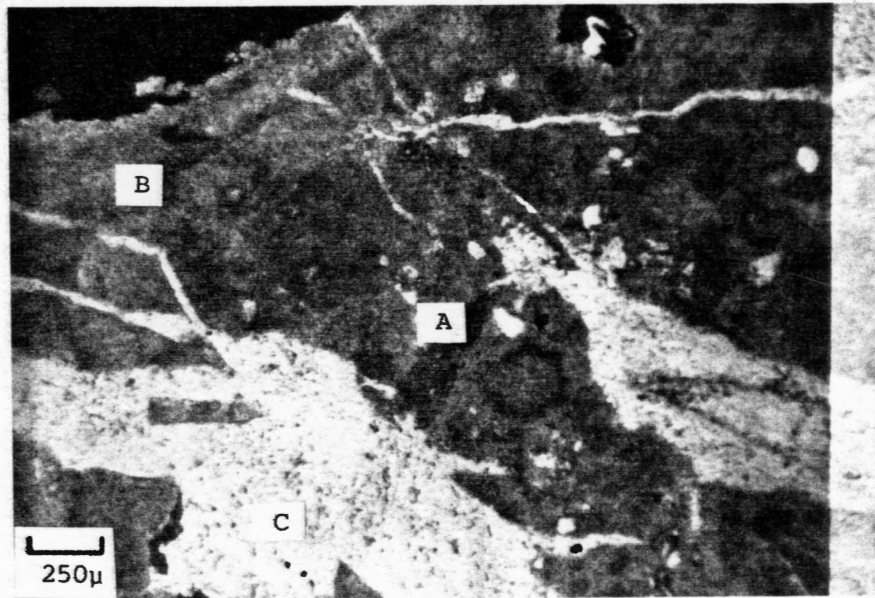


Plate 13. Slate chips (A), and brach valve in the host dolostone (B). Calcite (C) is seen filling the fissures - Gay's River  
 (A) 3.14 p.p.m. U (B) 2.171 p.p.m. U (C) .004 p.p.m. U



Plate 14. Track distribution of area seen in Plate 13 - Gay's River



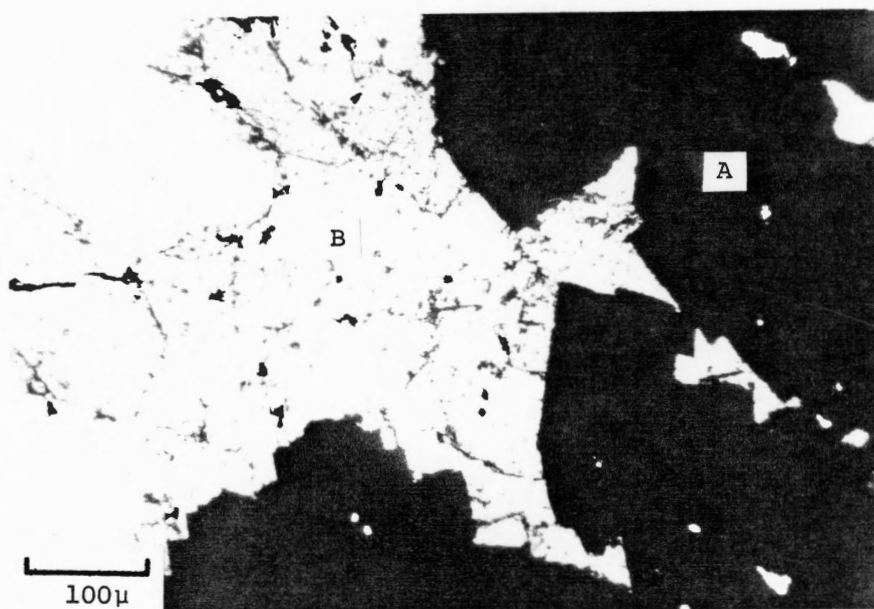


Plate 15. Coarse grained galena (A) in contact with  
 sparry calcite (B) - Pine Point  
 (A) .004 p.p.m. U (B) .749 p.p.m. U

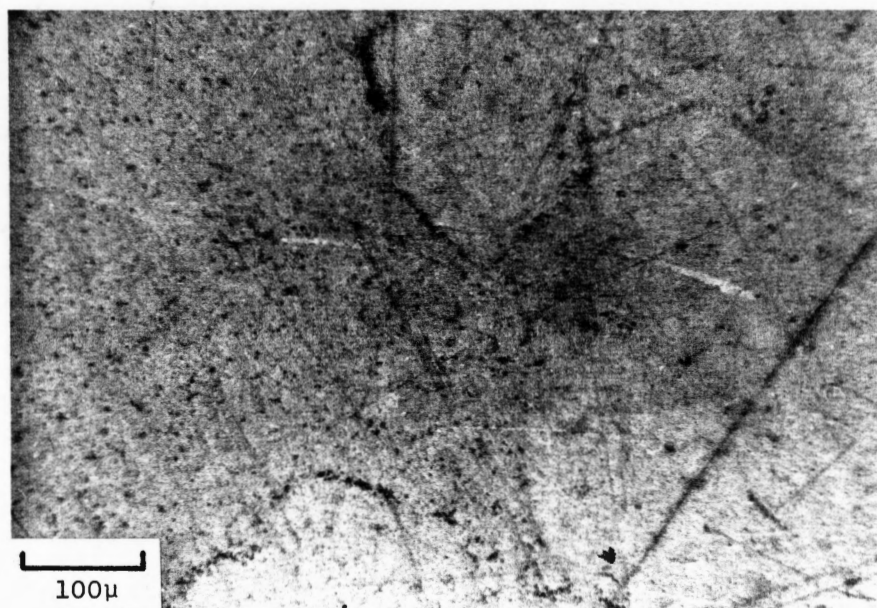


Plate 16. Track distribution of area seen in Plate 15.  
 Note concentration along the contact on the  
 galena faces - Pine Point

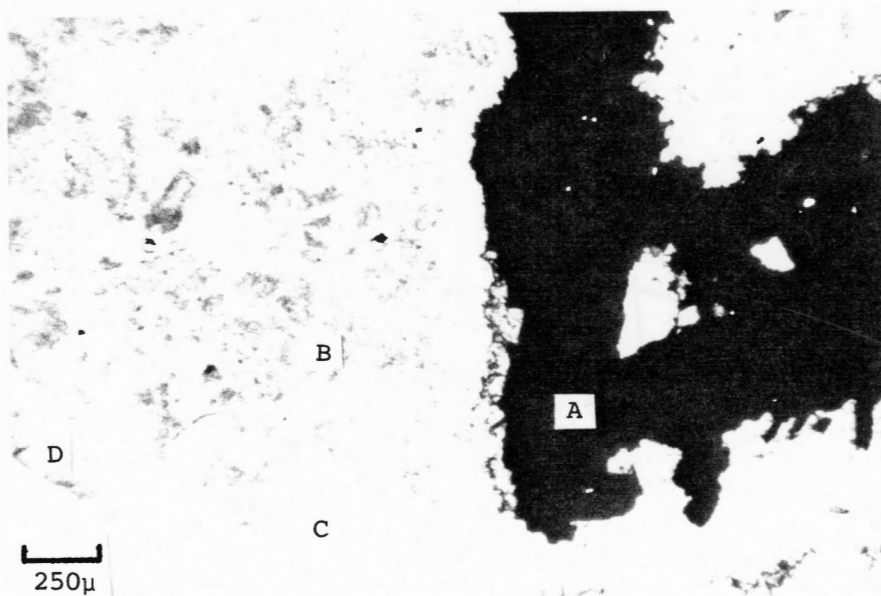


Plate 17. Galena (A) in contact with host dolostone (B) with calcite filling in the cracks (C). A state chip (D) is also found in one of the veins - Gay's River  
 (A) .001 p.p.m. U (B) 2.171 p.p.m. U (C) .004 p.p.m. U  
 (D) 3.14 p.p.m. U

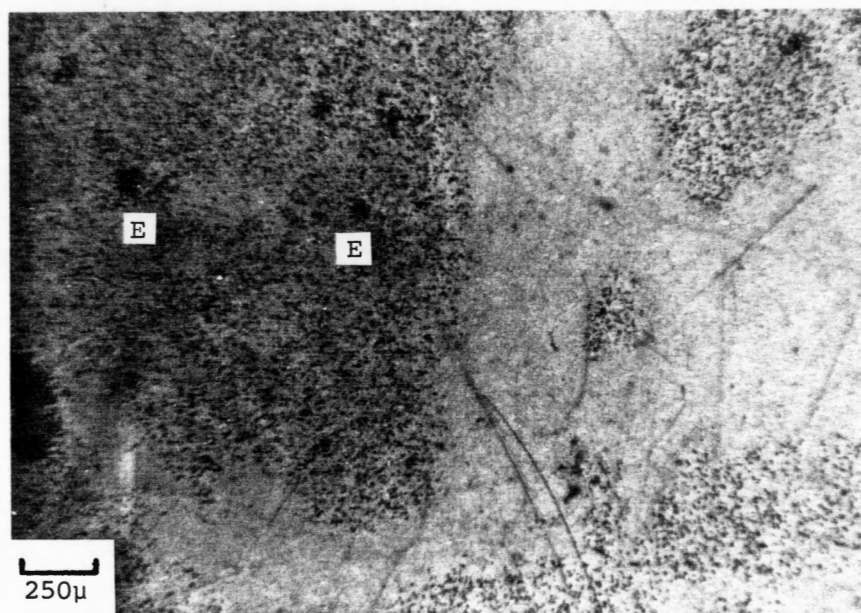


Plate 18. Track distribution of area seen in Plate 17. The 6 rosettes (E) are the result of quartz grains - Gay's River  
 (E) 5.56 p.p.m. U

## CHAPTER 5 - DISCUSSION OF RESULTS

Galena, Marcasite, Sphalerite

The most striking feature of the results shown in the previous pages is the extremely low uranium content of the three different metallic sulfide minerals encountered (galena, sphalerite and marcasite). These minerals are usually found protruding into pore spaces and also replacing the host dolostones. The average uranium content of these three minerals (Tables 3, 4, 5) is well below the assumed background of approximately 2 p.p.m. U for carbonate rocks.

The galena values are quite consistent (.002 p.p.m.) regardless of the occurrence of the mineral. The only relatively anomalous value (.206 p.p.m.) is derived from the bulk analysis pellets and is suspect, considering the consistency of the other galena results (see Table 3). Otherwise the galena is homogeneously uranium poor.

The sphalerite crystals occur in two distinct forms. Light grey distinguishable crystals are found in all four deposits. In the Polaris mine, sphalerite also occurs in brightly banded druses (Plates 1 and 2) and similarly in the Newfoundland Zinc deposit (Plate 7). These druses are extremely fine grained and individual crystals are indistinguishable. While all sphalerite, like the galena, is extremely uranium-poor (Table IV), the two types of sphalerite may be separated by uranium content also. The coarse crystalline variety contains an average of .422 p.p.m. (in all four deposits), while the finely banded cryptocrystalline variety contains an average of only .016 p.p.m. This may be the result of the

process which has been proposed to have formed the fine colour bands. The coarse grained inner sphalerite rims of the botyoids (Plate 7) appear to have crystallized from a different solution than did the microcrystalline sphalerite which coats them. Roedder (1968) suggests that the fine grained bands are the result of later stage groundwater fluctuations. If this has been the case then the difference in uranium content of the two sphalerite types may reflect a difference in uranium content of the hot mineralizing brine as compared with the cooler groundwater which followed. Although not significant economically, this does reflect a ten fold increase in uranium content. Interestingly, the fine grained bands are usually always found coating the coarse grained sphalerite.

Only in the Polaris mine was sufficient marcasite found for analysis. Like the other sulfides it too is extremely uranium-poor.

The extremely low uranium content of the galena is in complete contradiction to the results published by the Soviet scientific community (Plyushchev, et al., 1974). They have reported uranium contents in galena up to 20.8 p.p.m.

The low concentrations of uranium in all sulfide minerals examined is repetitive in four different deposits. This fact leads the author to assume that during crystallization in the M.V.T.D. environment, sulfide minerals reject uranium atoms. This low uranium content does not reflect, in the author's opinion, a lack of supply of uranium which could be incorporated. The uranium was there as is seen in the

carbonate results.

Uranium exclusion by the sulfide minerals is probably the result of its large ionic radius ( $0.97 \text{ \AA}$ ) (McKelvey, et al., 1955). This relatively large size combined with its fairly high valence state probably accounts for its limited substitution in most minerals. As mentioned previously, the only high abundance cation with approximately the same size ( $0.99 \text{ \AA}$ ) is Ca. Calcium is not found in any quantity in galena, marcasite or even the scavenger sphalerite. Thus the likelihood of uranium being found in the sulfide minerals is very low.

One area of coarsely crystalline light grey sphalerite in the Newfoundland Zinc deposit contains between .95 and 1.266 p.p.m. In light of the above discussion, this would certainly have been anomalous. The fission tracks observed to have originated from this area form numerous small configurations called rosettes. Rosettes contain anywhere from 30 to 300 tracks and are usually in the form of a crude circle, with the densest concentration of tracks being in the middle. Rosettes represent the track production by very small (usually) uranium rich grains. These grains are commonly inclusions of sphene, apatite or zircon. A uniform distribution of tracks over the surface of a crystal usually denotes the uranium content of that mineral.

The rosettes are located in two bands which run through the coarse grained sphalerite. This distribution suggests that the coarse grained sphalerite crystallized from a fluid which was enriched in uranium as mentioned previously (Plate 7). The rosettes may indicate the presence

of microinclusions such as apatite or zircon which were suspended in the mineralizing brine and hence were incorporated in the sphalerite crystals. Similarly they may indicate the position of the crystallization of mineral phases such as marine apatite which contains uranium as an isomorphous substitute. The uranium free crystals which later grew over the surface of the large grains apparently did not have access to the uranium and may have therefore crystallized from another solution as mentioned before.

However the crystals failed to yield the presence of any inclusions or apatite when analysed on the electron microprobe. The hand specimen from which the thin section was cut also gives no indication of having undergone two stages of mineralization. Collins (1973) in his report on the Newfoundland Zinc deposit does suggest, however, that two stages of mineralization did occur and therefore this could explain the distribution patterns of the rosettes in this section.

The other concentration of uranium is associated with galena crystals, found along a sharp contact between a zone of massive calcite and massive galena in the Pine Point deposit (Plate 9 and 10, 15 and 16, sample 00420 Appendix I). The uranium is evidenced by a line of tracks coinciding with several areas of this contact (Plates 9, 10, 15, 16).

The galena in this sample definitely grew before the calcite. Euhedral crystals of galena are observed protruding into the calcite. The calcite spar coats and fills in the intergranular pores in the galena.

The most plausible explanation for this accumulation is the absorption of uranium atoms onto the galena crystal faces. Once the galena had crystallized the later fluid which generated the calcite, filled the area. The calcite which crystallized contains 0.749 p.p.m. uranium and could easily have supplied uranium atoms. The uranium would likely have been in its oxidized ( $U^{+6}$ ) state and have been complexed to a carbonate radical. This high valence state would have facilitated the absorption process, if sufficient unsatisfied bonds existed on the galena surface.

Another possible explanation for this concentration is that a uranium rich fluid permeated along this contact after the calcite had crystallized. This seems unlikely because the fracture planes are not enriched in uranium at all, and the contact appears to be very tight (although it could have been resealed).

#### Carbonate Minerals

The carbonate minerals (dolomite and calcite) show the widest range of uranium concentration (Table VI) of all mineral species encountered (.002-8.43 p.p.m.). These minerals are almost omnipresent in all four ore zones but become less conspicuous as the ore grade becomes lower (a possible reflection of the porosity of the ore zones?).

Two deposits contain only dolomite spar, Polaris and Newfoundland Zinc. Pine Point contains both calcite and dolomite, and Gay's River has a predominance of sparry calcite.

As can be observed in Table VI, there is no consistency of uranium concentration, and spar species. Calcite is uranium rich at Pine Point while uranium poor at Gay's River. The dolomite is uranium poor at Pine Point and Newfoundland Zinc yet relatively uranium enriched in the Polaris deposit.

All the results are "normal" with respect to the average uranium content of the sparry carbonate species, except for three. The bulk analyses results of the Polaris deposit average just under 3.5 p.p.m. U for the dolomite. Similarly the dolomite of one thin section from Daniel's Harbour shows a range of .022 to 3.336 p.p.m. uranium within area of .5 cm<sup>2</sup> (Plate 11 and 12). These upper values are definitely anomalous considering a background of approximately 1 p.p.m. U for calcite. As mentioned previously, uranium does not substitute freely for Ca<sup>++</sup> ion in pure calcite because of the large charge difference (Ca<sup>++</sup> as compared to U<sup>+6</sup> in oxidized state). It is not known by the author what effect, if any, the addition of Mg<sup>++</sup> to calcite to form dolomite may have on this phenomenon. It is assumed to be slight. V. E. McKelvey, in an oral communication with C. L. Christ, states that uranium substitution can take place in the calcite lattice "where the (charge) difference can be accommodated by structural features" (McKelvey, et al., 1955, Pg. 468). It remains to be seen if the magnesium in calcite can create these special features to allow almost 3.5 p.p.m. uranium into the dolomite lattice.

The lack of uranium in the calcite and dolomite was expected. The presence of CO<sub>3</sub><sup>=</sup> and HCO<sub>3</sub><sup>-</sup> in the solutions from which these sparry



minerals crystallized would most certainly bind any available  $U^{+6}$  or  $U^{+4}$  in very soluble uranyl di and tri carbonate complexes, (U.D.C.  $-[(U^{+6}O_2)(CO_3)_2(H_2O)_2]^{-2}$ , U.T.C.  $[(U^{+6}O_2)(CO_3)_3]^{-4}$ ), in all but the strongest reducing environments. Another factor which must be discussed when dealing with these uranium complexes is temperature. Roedder (1967, 1977) states that these later stage calcite and dolomite spars are essentially formed between  $50^\circ$  and  $100^\circ C$  (from fluid inclusion evidence). The M.V.T.D., however, are usually formed between  $100^\circ$  and  $200^\circ C$  (approximately  $150^\circ$  Avg.). The uranyl di and tri carbonate complexes are unstable above  $120^\circ C$ . The solubility of uranium as the result of these complexes diminishes 100x (Rafalsky, 1958) between  $100^\circ$  and  $200^\circ C$ . The solubility of uranium, similarly, is high between  $25^\circ$  and  $100^\circ C$  with a maximum at approximately  $100^\circ C$ . Thus, the temperature at which the sparry minerals were formed is very important. From the fluid inclusion evidence it is suggested that the solubility of the uranium in the bi and tri carbonate complexes is near its maximum during spar formation. Therefore it is unlikely, considering the charge difference also, that much uranium could be incorporated into the calcite or dolomite structures.

The bulk analysis results from the Polaris deposit of 3.238 p.p.m. U in the dolomites is considered legitimate by the author. The repetition of the results appears to refute an explanation by contamination. The zonation of uranium content in the dolomite is another matter. The zone of highest concentration (3.336 p.p.m., Plate 11 and 12) is optically different from the other zones of dolomite. This area is covered by

a thin brown "smudge" which coincides exactly with the area of high track concentration on the detector. This smudge has been interpreted as the result of a zone of alteration which was moving through the sparry dolomite. Haglund, et al. (1969) reports that during diagenesis and fresh water alteration, carbonate sediments may become depleted by as much as 50% of its uranium. This uranium may be incorporated in mollusc shells, but more commonly passes through the system as part of a di or tri carbonate complex. If fresh water had access to the dolomite in the pore spaces, this uranium concentration in the "smudge" area may represent the remains of this fresh water and its dissolved uranium content. The uranium could easily have been leached from cracks and crystal faces. The uranium content of the unsmudged areas of the dolomite (between .022 p.p.m. and .424 p.p.m. U) indicates that there was sufficient uranium to be dissolved. The uranium may have been left due to evaporation of the groundwaters or some other mechanism leading to its precipitation. The area of lowest concentration (.022 p.p.m.) is surprisingly next to the most enriched. The area may represent the direction from which the waters moved. The area which contained .424 p.p.m. may be a zone which has been unaltered. The top right corner of photo 11 is the up direction. The meteoric water may have become entrapped in the bottom of the pore in the sphalerite, as it moved down due to gravity, and thus evaporated. High track densities are not found in the sphalerite in the next pore space (Plate 11).

The third anomalously high uranium concentration associated with carbonate spar occurs in a small vein of calcite cutting the host

dolostone at Pine Point (Plates 5, 6, and 8). This vein contains 8.43 p.p.m. of evenly distributed uranium. The distribution of the tracks rules out the possibility of inclusions. Dolomitization of the surrounding host rock may have released the uranium to the solutions which precipitated the calcite, but no explanation can be given as to how the calcite can incorporate almost 8.5 p.p.m. uranium. A detailed electron microprobe analysis failed to uncover any phase which could contain the uranium. The most likely explanation, considering the distribution of the fission tracks, is that the uranium is within the calcite crystals. This is inconsistent with the previous work, and no plausible explanation can be given by the author at this time.

#### Fluorite and Pyrobitumen

Fluorite was found only in the Gay's River deposit and is unexpectedly uranium poor (avg. .952 p.p.m. U). Baranov (1966) has stated that the uranium content of the fluorites increases with the degree of purple hue encountered. The fluorites of Gay's River showed exactly the opposite trend.

The low concentration of uranium in the pyrobitumen found in the Gay's River and Newfoundland Zinc deposits, is puzzling. Organic materials are well known for their ability to form organo-uranium complexes with the uranous ion and thus immobilize it. Such is not the case in either deposit. This is most logically explained by an absence of uranium at the time of deposition. Uranyl ions, complexed to the  $\text{CO}_3$  radical,

will be precipitated in the presence of organic matter (Hostetler, et al., 1962; Adler, 1974) because of the strong associated reducing environment. The most striking examples of this process are the logs of the Colorado Plateau which have been replaced by uraninite and montroseite. Therefore, it seems likely that the amount of uranium available to form complexes with the organic matter in either deposit must have been small.

#### Host Dolostone

As discussed in Chapter III, the amount of syndeposited uranium in carbonate rocks is generally low (Table I). The analyses of the four host dolostones reveals uranium concentrations well within the normally observed limits (Table IX). The only significant concentrations observed in the dolostones were associated with inclusions as proposed by Bell (1963). These inclusions are listed in Table 10.

The quartz and slate chips found in the host rock of the Gay's River deposit are expected, considering the nature of the basement rocks in the area (Plates 13, 14, 17, 18). The 5.56 p.p.m. U found in the quartz grains is definitely inconsistent with the normal behaviour of uranium. Uranium is much too large to be incorporated into the silica tetrahedron. When analysed on the electron microprobe, the grains yielded a makeup of pure silica. This point does remain as an enigma. The incorporation of 3.14 p.p.m. U into slate is not inconsistent with normal behaviour.

The low concentration of uranium in the biotite flakes suggests that these flakes contain no uranium-rich zircon. Zircon is well known for its ability to incorporate uranium.

## SUMMATION

The four deposits which were analysed for this thesis contain, on a whole, a diminutive quantity of uranium. Microscopically, uranium does occur in varying amounts related to the mineral phases present. Macroscopically, the hand specimens yielded no indication of uranium mineralization whatsoever. When subjected to analyses, using a gamma ray scintillometer, they failed to produce a reading above the assumed background of 20 counts per second. (Total analysis of U + Th + K.) On a whole, the results were below those expected. It may be concluded that the base metal ore zones from which these samples were removed are definitely non-uraniferous from an economic point of view.

## CHAPTER 6 - LIKLIHOOD OF URANIUM CONCENTRATION IN M.V.T.D.

These results are surprising. The deposits are so uranium-poor that the probability of uranium occurring economically in an M.V.T.D. appears infinitesimally small. Yet when one considers this possibility from a theoretical standpoint, this is not the case. If it can be established that the M.V.T.D. mineralizing environment is conducive to the transportation and deposition of uranium, the author is of the opinion that the possibility does exist for such an occurrence.

To establish this, an investigation of the geochemical characteristics of uranium deposits as well as M.V.T.D. was undertaken. In doing so, numerous geochemical similarities between M.V.T.D. and sandstone type uranium deposits becomes apparent.

Sandstone type uranium deposits rank second behind conglomerate hosted deposits (Witwatersrand, Elliot Lake) as the most important sources of uranium. They produce approximately 34% of the world's supply. The largest occurrences of this type are found in the Wyoming Basin and the Colorado Plateau in the western United States.

As mentioned previously, the geochemical conditions for the formation of these deposits are quite similar to those proposed to occur during M.V.T.D. mineralization. These similarities are displayed in Table 12.

The interesting conclusion that can be drawn from these similarities is that the brines which transport the metals in each case are nearly

Table 12. Comparison of M.V.T.D. and Uranium Deposits in Sandstones.

CHARACTERISTICS	URANIUM DEPOSITS IN SANDSTONES	MISSISSIPPI VALLEY TYPE ORE DEPOSITS
Source of Metal Ions	Alkali Granites, Tuffs, Magmatic Solutions, Expelled Sedimentary Water	Leached from Seds.. Meta. Mins., Ign Mins. Expelled Sed. Water, Seawater, Magmatic fluids?
Source of Transporting Fluids	Meteoric Water, Connate Water (Expelled Sedimentary Water) Volcanic Emanations	Meteoric Water, Connate Water, (Expelled Sedimentary Water), Volcanic Emanations
Medium of Transport	Meteoric Sweet Groundwaters, Dense Saline Brines, Slightly Acidic, Slightly Reducing	Igneous Brines, or Dense Saline Sedimentary Brines, Slightly Oxidizing, Acidic
Method of Complexing Metal	$Cl^-$ , $CO_3^{=}$ , $SO_4^{=}$ Complexes	$Cl^-$ , $S_2^{=}$ Complexes
HOST ROCK	SANDSTONES	CARBONATES
Temperature of Deposition	45° - 100°C	50° - 200°C
Pressure During Deposition	A Few Atmospheres	A Few Atmospheres
ASSOCIATED MINS.	MONTROSEITE, DOLOMITE CHALCOCITE, CHALCOPYRITE, CALCITE, FLUORITE, BARITE	FLUORITE, BARITE ARAGONITE, CALCITE, DOLOMITE, SIDERITE
Mechanism of Localization	Reduction	Reduction
Reducing Agents	Organic Material, Coal, Humates, Iron Oxide, Oxidation, $H_2S$ (Org. and Inorg), $CH_4$	Organic Material, Coal, Pyrobitumen, Humates, Hydrocarbons, $FeS_2$ Oxidation, $CH_4$
Characteristics of Host Rock	High Permeability, Porosity, High Organic Content	High Permeability and Porosity High Organic Content



identical. Theoretically, then, it appears as if uranium may be transported in the M.V.T.D. environment. Of course numerous other factors such as ionic strength and nature of dissolved constituents, etc. would play a complicating role. Yet if uranium is quite commonly transported and deposited in an environment which is geochemically almost identical to that which is found during M.V.T.D. mineralization, a good possibility does exist for the occurrence of uranium in a M.V.T.D.

The most critical factor, which is not mentioned above, is a source of the uranium. This criterion may be the underlying reason why major uranium concentrations do not occur in M.V.T.D. Only one such deposit is known, the Woodcutters-Rum Jungle deposit in Australia. Even here, there is a strong doubt that the base metal occurrence is a M.V.T.D. at all. Three sources are proposed.

The most logical sources of uranium for such a deposit are exposed alkali granitic rocks and tuff horizons. These rock types have long been proposed to supply the uranium source found in sandstone-type uranium deposits. The uranium is usually contained in the refractory minerals of plutons and in the glass of tuff layers. The release of this uranium supply (up to 200 p.p.m. in some tuff horizons) is ascribed to the activity of hydrothermal solutions and devitrification. Gabelman (1977) presents very good arguments as to why these rocks should not be considered a good source of supply of uranium. A great deal of controversy exists on the leachability of volcanic glass. This author is of the opinion that it is quite low, and agrees with Gabelman that the tuff leach

hypothesis should not be used unless good quantitative data is made available to the contrary. M. Zentilli suggests that this leachability may be higher than expected due to the devitrification process, although no data is available at present (M. Zentilli, personal communication). Refractory minerals such as sphene zircon apatite, etc. are on the other-hand quite leachable in dilute acids in the laboratory and therefore granites could still prove to be a viable source rock.

Another source of uranium is magmatic hydrothermal solutions. These solutions are definitely the source of numerous vein-type deposits. Yet fluid inclusion evidence for both M.V.T.D. and sandstone-type uranium deposits indicates that these solutions took no part in the mineralization processes. Coleman (1957) proposed that the mineralization temperature for the Colorado Plateau ores was approximately 100°C. Gabelman (1977) determined it to be approximately 50°C. Roedder (1977) has suggested a range between 45°C and 100°C from fluid inclusion studies "similar to inclusions found in Mississippi Valley base metal, barite, fluorite, ores" (Roedder, 1977). Roedder also lists the ore forming temperatures of 48 major M.V.T.D. These range from 40°C to 225°C with the vast majority being in the 100 to 150 range. These temperatures are much too low to have been the direct result of magmatic solutions, unless considerable cooling has taken place in every case. Therefore the role of hydrothermal solutions in supplying uranium to these deposits is considered to be minimal.

The last popular source of uranium which could supply a M.V.T.D.

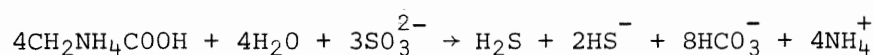
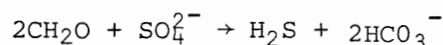
mineralizing brine is the expelled water (connate) of sedimentary rock sequences. The lithologic units which are most likely to contain the uranium are clay and shale beds. The uranium is absorbed onto the surface of clay particles or held by organo-uranium bands in the more organic rich layers. This uranium is syngenetic with the sediments and usually is found in concentrations up to 4 p.p.m. (Saxby, 1970). The uranium is expelled from the sediments by desorbing in the pore space fluids in response to compaction pressures. These fluids, once expelled, usually migrate updip towards zones of lower pressure. Conceivably, enough uranium could be supplied in this way to form a substantial accumulation.

The expelled connate water theory is one of the leading explanations of the origin of the ore forming solutions of M.V.T.D. Jackson and Beales (1967) have refined and applied this theory to the Pine Point deposit. The fluids which result from this process correlate very well with those conditions set down by fluid inclusion studies (T. P. Density, sal.). As discussed previously, these conditions are conducive to the simultaneous transport of any uranium, lead or zinc molecules made available by the same process. Conceivably, a M.V.T.D. brine formed by sediment dewatering could be enriched in uranium by the same process.

Uranium supplied to a brine would be transported in  $\text{CO}_3^{=}$ ,  $\text{SO}_4^{=}$  and  $\text{Cl}^-$  complexes as discussed previously. The temperatures of such a brine (50°C - 150°C) would be well within the stability of the uranyl carbonate complexes (U.D.C., U.T.C.). The slightly oxidizing conditions normally found in M.V.T.D. brines would tend to render the uranium even more soluble, as would the slightly acidic pH.

The high solubility of uranium under these conditions may prove to be the reason why it is not normally found deposited in M.V.T.D. Very strong reducing conditions are required to remove uranium from solution when it is bound in the U.D.C. and U.T.C. complexes. Reducing conditions are also required to initiate deposition of the lead and zinc sulfide minerals in M.V.T.D. The reducing capacity normally attributable to M.V.T.D. ore zones should, in theory, be capable of reducing uranyl ion to uranous ion and thus initiating deposition of uranium minerals. Unfortunately, no quantitative data was available to compare the behaviour of uranium in strong reducing environments which was gradually being enriched in the  $\text{CO}_3^{=}$  species. Therefore no conclusions may be reached on which has the more effect on the behaviour of uranium,  $\text{CO}_3^{=}$  or reducing conditions.

The reducing environment in the M.V.T.D. ore zone is usually the result of the presence of organic matter. This is usually found in the form of algae, fluid hydrocarbons, and decaying detritus. Decomposed originally by fermentation, they are usually attacked by anaerobes (*desulfovibrio*) which convert the organic constituents and inorganic  $\text{SO}_4$  into energy producing products.



This produces an environment where the Eh can become as low as -500 mv. The process liberates  $\text{S}^{=}$  which combines with  $\text{H}_2$  to form  $\text{H}_2\text{S}$  gas.  $\text{CH}_4$  can act as an inorganic reducing agent but the process

is slow. Lead, zinc and uranium are all susceptible to reduction and are immobilized by the process. The uranium and vanadium minerals which could be formed in such an environment include uraninite ( $U^{+4}O_2$ ) and montroseite ( $V_2O_3 \cdot H_2O$ ). Coffinite ( $U(SiO_4) \cdot (OH)_4$ ) would form instead of uraninite in an environment containing excess silica.

The organic materials which formed the reducing environment are rarely found in large quantities in the ore zones. The fluid hydrocarbons are usually thermally solidified to pyrobitumen (as in Gay's River and Daniel's Harbour). The organic solids are oxidized to  $CO_2$  and reduced to  $CH_4$  which are volatile. Subsequently, these gases are seldom found accompanying the ores because of their tendency to escape.

Uranium mineralization may also occur in M.V.T.D. in the form of efflorescent deposits. These types of deposits should be restricted to karsted terrains which offer numerous cave walls onto which the minerals could be deposited. Uranyl sulfates and chlorides (see Fig. 10) would most likely be the ore minerals of such deposits. Although this type of mineralization does occur, reduction is assumed to be the major Pb, Zn, and possibly uranium ore forming process.

Uranium mineralization of the types discussed above does not necessarily have to occur with the M.V.T.D. mineralizing brine or lead zinc ores at all. Uranium may be concentrated in its own brine and deposited in the limestones by itself with no other associated ores. This is what occurred in the Grants deposit in New Mexico. A uranium rich brine

or fluid percolated upwards into a fetid limestone which resulted in the deposition of uranium minerals by reduction.

Criteria which would Enhance the Chances of Locating a Uranium Deposit in a M.V.T.D. Environment

1. The reducing environment which is responsible for the localization of the uranium would be optimally located near the edge of the carbonate sequence. This is necessary so as to minimize the amount of  $\text{CO}_3^{=}$ ,  $\text{Cl}^-$ , and  $\text{SO}_4^{=}$  which can be dissolved by the brine as it moves into the carbonates. The lower the concentration of the species the milder the reducing environment necessary to immobilize the uranium.
2. The limestone sequence should preferentially be underlain by a porous sequence, such as sandstone, which would allow access by the mineralizing fluids. Ideally, the sequence could be composed of aquifer sands enclosed by aquiclude shales. Thus, the flow of the brine would be concentrated in one area rather than tend towards dispersal as is normally observed.
3. An area of excessively high or low geothermal gradient which could influence the temperature of the mineralizing brines would tend to minimize the solubility of the uranium by reducing the stability of the U.T.C. and U.D.C. complexes. This would permit the uranium to

be immobilized by weaker and weaker reducing environments. The activity of high temperature igneous brines would be especially conclusive to the formation of such deposits. The lack of uranium in M.V.T.D. may be a reflection of the lack of igneous activity in the ore forming processes of most deposits.

4. Logically an area which is being explored for such a uranium deposit, should contain possible source rocks such as exposures of uraniferous tuffs and granites (if they are leachable). These rock types would definitely enhance the possibilities of meteoric enrichment. Similarly a sedimentary sequence known to contain dark organic rich shale beds could provide such a source rock.
5. The potential host sequence should exhibit signs of having been enriched at one time in organic material. This would be evidenced by the occurrence of solid pyrobitumens, methane, and fluid hydrocarbons. The presence of  $H_2S$  in fetid rocks would probably be the best indicator.
6. The area of regional exploration should be located close to the continental cratons and not in the forelands. This is suggested because of the affiliation of uranium deposits with the crystalline basement rocks (Gabelman, 1977).

The above discussion indicates that if the uranium is available to the M.V.T.D. brine, it should be precipitated in spatial association with the lead-zinc metallic sulfides. The extremely low concentrations

found in the four deposits suggest that the ore forming brines did not have access to appreciable supplies of uranium. This conclusion is opted for rather than suggesting a lack of reducing environment, etc. for one main reason. If the uranium had been available to a brine, it seems unlikely that it could have passed through the strongly reducing environment, which was producing sulfide minerals, without leaving behind a concentration higher than 8 p.p.m. Even if the reducing environment which precipitated the metallic minerals was almost completely oxidized before the arrival of the uranium, almost certainly the uranium would have betrayed its presence in a few isolated pockets.

The lack of any appreciable uranium enrichment in 99.9% of the known M.V.T.D. completely contradicts the theories proposed above. Although the author has demonstrated through association that enrichment could occur, it does not. The question of why it does not has yet to be answered. A lack of a source rock cannot realistically be used to explain the absence of uranium in all M.V.T.D. Perhaps the answer lies in the fact that so many physical and chemical requirements would have to be met coincidentally for such a deposit to form. Yet Mississippi Valley Type Deposits form by the coincidence of the same requirements.

The above discussion is presented to promote debate on the subject of why uranium is not incorporated into these deposits. If and when the answer is found, such an affiliation may prove to be an added bonus to an operation which was considered to be working just another M.V.T.D.



## RECOMMENDATIONS

The obvious follow-up to this study is a detailed analysis of the partition of uranium in a Mississippi Valley type deposit which has been formed by the activity of a volcanogenic brine. The well known association of uranium with higher temperature ore and rock types (granites, pegmatites, tuffs, vein deposits, etc.) suggests that the concentration of uranium should be significantly greater in such a deposit. A better understanding of the behaviour of the element in the higher temperature environment may eventually provide the answer to a very important question: why does uranium prefer the continental copper and vanadium association as opposed to the marine lead-zinc environment? An investigation into the geochemical circumstances which inhibit the incorporation of both Cu and uranium into the M.V.T.D. environment should prove to be very useful to the concepts of ore formation.

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## APPENDIX I

Following are the sample descriptions of those specimens used in this presentation.

Pine Point

- 00410 Specimen is 12 cm. long, 7 cm. wide, 5 cm. thick, composed of alternating bands
- bottom 4 cm. massive galena (anhedral to subhedral) with minor interstitial sphalerite (5%) and calcite (5%)
  - 4 cm. massive sparry dolomite (anhedral to subhedral) crystals to .75 cm. The four cm. are composed of alternating 1 cm. thick bands of milky white dolomite and dark grey blue
  - 2 cm. holocrystalline dark grey host dolostone
  - 2.5 cm. alternating bands of dark grey blue and milky white dolomite as above
  - 1.5 cm. massive dark brownish black sphalerite, subhedral to anhedral xls to .25 cm. Contains minor calcite

These bands are sometimes interrupted by long thin vugs lined by sparry dolomite 5 cm. long, 2 cm. thick, which occur along the contacts between bands. Otherwise the contacts between bands are sharp and flat. These vugs give a porosity of approximately 10%.

- 00412 Specimen is 7 cm. long, 4 cm. wide, 2½ cm. thick
- composed entirely of sparry anhedral to subhedral milky white



- dolomite crystals. These crystals are up to 3 mm. long
- contains approximately 5% vugular porosity lined with sparry dolomite

00416 Specimen is 5 cm. long, 4 cm. wide, and 2 cm. thick

- light grey dolostone, fine grained, sandy, relatively featureless
- contains thin (2 mm.) dark brown organic looking streaks which may or may not be coated with galena
- one large vug ( $2\frac{1}{2}$  x 2 cm.) lined with sparry dolomite. Small galena and pyrite cubes (euhedral to subhedral) are found coating the sparry dolomite
- weathers grey black
- groundmass (dolostone) highly recrystallized

00418 Specimen is 6 cm. long, 6 cm. wide, and 3 cm. thick

- light brownish grey, fine grained, well sorted limy dolostone.
- one corner composed of a pocket of euhedral white to clear calcite rhombs
- contains <1% galena, which is found disseminated along fracture planes
- contains 1-2% sphalerite, honey yellow, found as patches on fracture planes. Also 3 large subhedral sphalerite crystals (up to 3 mm.), dark grey brown in calcite
- groundmass is very recrystallized and weathers grey black

- 00419 Specimen is 9 cm. long, 4 cm. wide, and 5 cm. thick.
- light brownish grey, fine grained dolostone, with <1% sandy detritus
  - approximately 25% vugular porosity lined with large euhedral, white calcite xls (8 mm. - 10 mm.)
  - 1 small (2 mm.), dark brown sphalerite crystal in vugular calcite
  - very finely disseminated galena found in patches along fracture planes
  - <1% thin (<1 mm.), dark grey (organic?) stringers

- 00420 Specimen is 9 cm. long, 5 cm. wide, and 5 cm. thick.
- bottom 1/3 coarse grained euhedral to anhedral sparry calcite (to 3 mm.) with no sulfide mineralization
  - top 2/3 90% massive euhedral to subhedral coarse grained (to .5 cm.) galena -10% interstitial white calcite and dark brown black sphalerite (1.5 cm.) infilling between galena crystals
  - the contact between the two zones is irregular but very sharp

Gay's River

- G.R.22 Specimen is 11 cm. long, 11 cm. wide, and 2 cm. thick
- light brownish grey, fine grained dolostone (limy)

- approximately 5% subhedral calcite crystals (white to clear, 1 mm.) disseminated throughout.
- approximately 1% large (to 1 cm.) calcite crystals (white euhedral to subhedral) in one area (2 cm.-2 cm.)
- one area of petroliferous black stain (3 cm.x 5 cm.) which reacts strongly to Hcl
- 1% honey yellow sphalerite, disseminated in small blebs (1 mm.) throughout
- 2% purple euhedral fluorite in a few small blebs (2 mm.) and as the centre of the petroliferous area - apparently grows in a stockwork with the inner stringers of the petroliferous area
- porosity is <1% pinpoint

G.R. 2 Specimen is 10 cm. long, 4 cm. wide, 3 cm. thick

- light grey brown dolostone
- <1% thin stringers (stylolites)
- 2% honey yellow sphalerite disseminated in small blebs (1 mm.)
- 1% purple fluorite in disseminated blebs (1 mm.)
- approximately 3% pinpoint porosity

G.R. 4 Specimen is 8 cm. long, 6 cm. wide, and 6 cm. thick

- light greyish brown dolostone
- 1% thin organic looking stringers
- 1% disseminated honey yellow sphalerite in small blebs (1 mm.)

G.R. 4 - 1% calcite filling small vugs (1 mm.) disseminated throughout  
- approximately 2% pinpoint porosity  
- 2 small unidentified brachiopod valves (single) seen in cross section

G.R. 5 Specimen is 5 cm. long, 3 cm. wide, and 3 cm. thick  
- light greyish brown dolostone containing 1% white calcite in minute pores (1 mm.)  
- 1% disseminates purple fluorite, in minute blebs (<1 mm.)  
- 5-10% euhedral to subhedral disseminated galena (1-2 mm.)

G.R. 9 Specimen is 10 cm. long, 4 cm. wide, and 5 cm. thick  
- light grey fine grained dolostone containing  
- 10% skeletal debris - mostly brachiopod valves, few clams, bryozoans  
- 10% disseminated galena, in veinlets, and also filling pores in the brach valves  
- 5% honey yellow sphalerite in minute pores (2-3 mm.)  
- 1% white sparry calcite filling small pores  
- porosity <1% pinpoint and shelter. Galena seems to form veinlets in places paralleling thin wavy stylolites

G.R. Specimen is 4 cm. long, 5 cm. wide, and 5 cm. thick  
- very light brown fine grained limy dolostone containing

- G.R. - <1% disseminated purple fluorite filling pores (2 mm.)
- <1% fine grained white calcite filling pores (2 mm.)
- 25% black petroliferous stain covering the host rock
- 1% honey yellow sphalerite filling the minute pores (<1 mm.)
- porosity approximately 5% pinpoint
- G.R. 1 Specimen is 4 cm. long, 5 cm. wide, and 2.5 cm. thick
- very light brown, fine grained limy dolostone containing:
- 2% disseminated honey yellow sphalerite
- approximately 10% white sparry calcite found on one end  
(2 cm. x 2.5 cm. by 2.5 cm.)
- 5% dark black petroliferous stain on the other end
- no fossils or galena
- porosity <1% - vugular ≈.5 cm., usually lined with sphalerite  
or calcite

Newfoundland Zinc

- 00815 Specimen is 13 cm. long, 11 cm. wide, and 6 cm. thick
- dark grey dolostone weathered light brown
- subhedral to anhedral sphalerite composes lower 1/3 of sample,  
light brownish green and massive (crystals to .3 cm.)
- sphalerite is also found disseminated in the dolostone
- dolostone is fine grained

00816 Specimen is 30 cm. long, 12 cm. wide, and 8 cm. thick

- light grey massive, fine grained limestone
- contains no sulfide mineralization
- thin calcite stringers are found filling the fracture planes
- curious weathering - weathers out like a sponge - may be leaving organic rich layers behind

00817 Specimen is 20 cm. long, 14 cm. wide, and 9 cm. thick

- patchwork composed of:
  - 20% dark grey, fine grained dolostone bands
  - 40% light greyish brown, fine grained sphalerite masses up to 1.5 cm. in diameter
  - 40% white sparry dolomite - the pores between the sphalerite and dolostone bands are either completely filled or lined with euhedral to subhedral sparry dolomite
- the sphalerite masses are sometimes cored with dolostone - the sphalerite is growing colloformly around the dolostone host rock fingers

00818 Specimen is 13 cm. long, 10 cm. wide, 9 cm. thick

- this specimen is much the same as sample 00817 - a patchwork of dolostone fingers coated by sphalerite. The pores are again lined or filled with sparry dolomite

Polaris Deposit

- 00479 Specimen is 10 cm. long, 9 cm. wide, and 8 cm. thick
- composed almost entirely of colloform growths
  - the core of these growths seems to be light brown dolostone, around which has grown thin layers of sphalerite (light brown to grey black), along with the occasional band of anhedral galena
  - porosity approximately 5% vugular - the exposed sides of these vugs are usually lined with thin bands of sphalerite and the occasional crystals of subhedral marcasite
  - the occasional large (.5 cm.) euhedral galena crystals are found growing between the colloform sphalerite heads
  - the sphalerite laminations on the colloform heads range in thickness from .5 mm. to .5 cm.
- 00482 Sample is composed of small crushed pieces (.5 cm. - 3 cm.) of the lithology described for sample 00479 - sphalerite colloform growths around dolostone, with marcasite and galena filling in the intergranular pores.
- 00526 Composed almost entirely of both sphalerite and marcasite colloform growths.
- these druses are cored by dark green, fine grained dolostone
  - the pore spaces between the druses are both lined and filled by euhedral galena (up to 1.5 cm.), sphalerite (yellow brown

00526 to dark black, up to 2 mm.), and sparry euhedral dolomite  
(creamy white, up to 2 mm.)

00563 Specimen is 11 cm. long, 8 cm. wide, and 5 cm. thick  
- much the same as sample 00479 - composed entirely of colloform  
sphalerite (druses have cores of dolostone) with the inter-  
granular pores lined and filled with marcasite, galena, and  
sphalerite bands