A COBALT-TUNGSTEN DEPOSIT IN THE SUDBURY DISTRICT

A
THESIS

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Science of McGill University in partial
fulfilment of the requirements for
degree of Master of Science

by

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INTRODUCTION

Since the discovery of the famous mineral deposits of the Cobalt and Sudbury districts, the surrounding area (part of the Temiskaming sub-province of the Canadian Shield) has received considerable attention, including systematic and detailed geological mapping in the more important districts, and intensive prospecting throughout the area. Under such circumstances it is not surprising that, in a well-mineralized area, many mineral deposits have been discovered. Detailed studies of many such properties have yielded new and important information on minerals and mineralizing processes.

Some deposits in this area have become important producers, others, after considerable development, have proved of no economic value. The Fielding property is one of many which, to date, has failed to yield ore bodies. However, the mineral association here is definitely of academic, if not economic, interest.

The presence of considerable amounts of cobalt and tungsten minerals serves to distinguish the property from the more common copper-nickel deposits of the area. In an effort to obtain further information on this unusual mineral association, this study of the Fielding property was undertaken as a thesis problem.

The investigation is less complete than desired, chiefly because the writer has not been able to visit the property. Accordingly, no first-hand observations on the field relationships are possible. Furthermore, the suite of specimens on which the study is based was not collected primarily for this purpose, and has certain deficiencies, e.g., the relatively unaltered county rock type away from the mineralized zone. Despite these limitations, the description of the unusual mineral association and some conclusions derived therefrom are regarded as worthwhile contributions.

ACKNOWLEDGMENT

The author is indebted to Mr. J.J. Lyons for his excellent description of the property and for the suite of specimens on which this study is based. Helpful criticism and supervision by Dr. A.W. Joliffe proved invaluable, both during the actual study and in the preparation of the manuscript.

LOCATION

The property is located in Lot 10, Concession V, Foster Township, Sudbury District, Ontario, between the Vermillion River and Lake Brazil (see plate I), about six miles east of the town of Espanola, and is owned by Mr. G.E. Fielding. The Sault St. Marie-Sudbury line of the Canadian Pacific Railway lies about three miles north of the claims. Two roads pass within a mile of the property. One from Espanola to Lake Panache passes south of Lake Brazil. The other extends south from the main Sudbury-Espanola highway. The property includes one patented claim (No. S-4875), of some thirty acres, and an adjacent fifteen "protection" claims totalling about 700 acres in all.

GENERAL GEOLOGY

The Espanola area was mapped geologically by T.T. Quirke in 1914-15. More recently (1938) a geologic map including the northern part of the Espanola area (and the Fielding property) has been published, but is essentially a compilation of earlier work by Collins and Quirke. Plate I and the description of the formations shown on it are based upon Quirke's 1917 report.

Quirke, T.T. "Espanola District, Ontario." Geol. Survey Canada. Mem. 102, 1917

Collins, W.H. and Quirke, T.T. "Map 291 A. Espanola Sheet, Sudbury District, Ont."

TABLE OF FORMATIONS

PLEISTOCENE and POST-PLEISTOCENE	clays, gravels and boulder clay.
KEWEENAWAN	diabase dikes and sills.
HURONIAN	Gowganda formation Unconformity Serpent Quartzite Espanola Group Espanola limestone Espanola greywacke Bruce limestone Bruce conglomerate Minor unconformity Mississagi Quartzite

MISSISSAGI QUARTZITE

Mississagi quartzite outcrops along the Spanish River about two miles southeast of Espanola. From this point it forms a broad band two miles in width striking N. 70°E, until it disappears from the N.E. corner of the Espanola sheet, in the vicinity of Lake Wabagizig.

Included in the Mississagi quartzite is a conglomerate phase carrying pebbles and boulders of granite, quartz, schist and greywacke, enclosed in a matrix of coarse gritty to fine-grained quartzite.

The quartzite proper is rather variable. In some places it is coarse-grained, arkosic, and cross-bedded, in other places it is highly quartzose and so thoroughly re-cemented that individual grains cannot be distinguished megascopically. In other localities the quartzite has been much fractured and the openings have been filled with quartz veins. In lots 1, 2 and 3, Concession VI, Foster Township, the quartzite is highly fractured and irregular in strike.

The thickness of the basal conglomerate of the Mississagi formation appears to be considerable in the Espanola area, but Quirke found it impossible to estimate it with any degree of certainty. The true quartzite is believed to be at least 4000 feet thick.

BRUCE CONGLOMERATE

Bruce conglomerate outcrops just south of the junction of the Spanish River with the Vermillion River, and scattered exposures are found throughout a belt about a mile wide extending easterly across Foster Township.

Quirke believes that there is a slight unconformity between the Mississagi quartzite and the Bruce conglomerate, and, whereas it is apparently conformable at some places, it shows an angular discordance of as much as 22° in dip at others.

The Bruce conglomerate is a boulder and pebble conglomerate, massive in some places and roughly stratified in others. The pebbles are of pink or grey granite, quartz and quartzite, with some pebbles of conglomerate and a few of schist. The gritty matrix has a great number of quartz grains up to the size of peas scattered throughout a dense dark green background, and may be massive or distinctly bedded. The thickness of the Bruce conglomerate has been estimated at 400 feet.

ESPANOLA GROUP

The Espanola group consists of three formations, the Bruce limestone at the base, a fine grained greywacke and slate (Espanola greywacke), and a thin upper calcareous member known as the Espanola limestone.

Members of the group outcrop at intervals in a band about a mile wide extending through Lake Brazil, westward through Lake Tulloch, and thence S 70° W for about five miles. From Lake Brazil the band strikes east past Lake Elizabeth and then strikes N 80° E. Another band striking NE - SW. lies one mile south of Lake St.Leonard.

The Bruce limestone is separated from the Bruce conglomerate by a 6 foot band of greywacke. The contact of the greywacke with the conglomerate is sharp and well defined, and apparently conformable. The limestone is often

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The Bruce limestone is separated from the Bruce conglomerate by a 6 foot band of greywacke. The contact of the greywacke with the conglomerate is sharp and well defined, and apparently conformable. The limestone is often altered to a white marble, and is in most places markedly siliceous. It is red weathering and characteristically thin-bedded. The limestone is nearly everywhere covered by overburden. Its thickness is about 150 feet.

The Espanola greywacke lies conformably upon the Bruce limestone. The weathered surface of this formation has a deep rough lineation resulting from the interlamination of soluble calcareous argillites with insoluble siliceous layers. Beds seldom exceed an inch in width. The greywacke is very incompetent and in many places is extensively crumpled. Like the Bruce limestone, good exposures are scarce, the greywacke generally being marked by lowland and swamp. The folding of this incompetent horizon has rendered accurate measurements impossible, but its estimated thickness is 280 feet.

The Espanola limestone grades upward and downward into greywacke. The transition into the Espanola greywacke below consists of an interbedding of dark green, almost black greywacke layers with pale green limestone. In the limestone proper the beds range from one-tenth of an inch to an inch in thickness, and are often lenticular. These beds are siliceous and in places grade into quartzite. It is more resistant to weathering than the other members of the group. Although the maximum thickness of the formation is only 25 feet and in places it thins down to a foot, it is a useful marker for correlation purposes.

SERPENT QUARTZITE

A broad band of Serpent quartzite strikes east-west across the southern half of the area shown in Plate I. This band continues westward to the vicinity of Apsey Lake, three miles west of the Algoma Eastern Railway. From Lake St. Leonard it strikes northeast along the north shore of Lake Panache.

The Serpent quartzite consists of two members, a basal member of fine-grained greywacke gradational downward into Espanola limestone, and an upper arkosic member. The upper part of the greywacke shows excellent ripple marks and mud cracks, which are well preserved in thin greywacke layers between beds of clean quartzite. The whole member is somewhat calcareous and limestone beds are found in the lower portion. The thickness is estimated at 250 feet.

The upper member consists of interbedded arkose, greywacke, and quartzite, and the alternating beds impart a characteristic banded appearance. The quartz content ranges up to 50% and the feldspar content is in places as high as 75%. A small amount of carbonate is generally present. The formation appears less metamorphosed than the Mississagi quartzite; the arkosic members are almost free of sericite. The Serpent quartzite in Foster Township may have a thickness as great as 8,000 feet.

GOWGANDA FORMATION

In the Espanola area the Cobalt series is represented by the Gowganda formation only, which in the area shown in Plate I, is found one-half mile southeast of Lake St.Leonard. The small extent of the quartzite in this area is a result of its being cut off to the south and southwest by faults.

The Gowganda formation consists of a basal conglomerate which lies unconformably on the Serpent quartzite, and grades up into well-bedded slate, which in turn is succeeded by a massive slate conglomerate which looks like a tillite. The character varies somewhat from place to place. The lower conglomerate is very pebbly and bouldery near the contact with the Serpent quartzite, but is gradational into the overlying slates.

The slate member contains numerous beds of greywacke and is gradational into the overlying conglomerate. In the Lake St. Leonard area the top of the Cobalt is represented by a fine pink arkose, which may be the base of the Lorraine quartzite formation. Quirke estimates the thickness of the Cobalt sediments in the area as 1,350 feet.

KEWEENAWAN DIABASE

Dikes and sills of Keweenawan diabase cut the other Precambrian rocks. There are numerous masses of this diabase irregularly distributed throughout the area, for the most part striking parallel to the enclosing formations. A more complete discussion of the diabase is reserved for the section on petrography.

PLEISTOCENE AND POST-PLEISTOCENE

Pleistocene deposits are few in the Espanola district, but thick post-pleistocene sediments cover much of the area. The majority of these deposits are stratified lake deposits, consisting of sands and stratified clays. Along the Spanish River near Espanola sand exposures show a thickness of 80 feet.

STRUCTURE

Quirke interprets the general structure of the area as consisting of a basement of pre-Huronian rocks overlain by a south-facing homocline of Huronian formations cut by Keweenawan diabases, and interrupted by several reverse faults and one normal fault.

LOCAL GEOLOGY

The extent of the Fielding Property is shown on Plate 1. The northern part of the property is underlain by white feldspathic quartzite of the Mississagi formation; immediately to the south of this lies a band of Bruce conglomerate. The southern part of the property is underlain by limestone and silt beds of the Espanola formation. These rocks are cut by Keweenawan diabase, which outcrops along the northern half of claim S-4875, and forms a ridge about 60 feet high along the east-west centre line of this claim.

The diabase, as mapped by Quirke, is in the form of a large dike or sill, with the outcrop width ranging from 1000 to 2500 feet. The general strike is about N 70° E, nearly parallel to the sediments which it cuts. The dip is unknown. The diabase extends 2½ to 3 miles S 60° W, to the Algoma Eastern Railway near Lake Tulloch, and for about 1½ miles due east from claim S-4875.

No faults or shear zones were found during general traversing of the property by J.J. Lyons. Both the sedimentary rocks and the diabase are well jointed, but are otherwise quite massive. The joint systems show two regional strikes, N20°W and N20°E. Both sets dip vertically.

On claim S-4875 (see Plate II) the diabase is cut by a vein of barren glassy blue-white quartz. The vein strikes about N20°W, dips between 70° and 80° to the west, and varies in width from 8 feet to 100 feet. As it approaches the southern part of the diabase outcrop it appears to swing to about S20°E, and is exposed for 150 feet in this direction before it disappears beneath the overburden. The known length of the quartz vein is about one-half mile.

Prospecting carried out along the vein revealed only two showings. One of these is the site of the main pit on claim S-4875; the other lies about 1000 feet to the north, where a few stringers of massive pyrrhotite are found in glassy quartz.

Two aplite dikes were found cutting the quartz vein (Plate II). Their relation, if any, to the mineralization, is not known.

DEVELOPMENT

The early development carried out 20 to 25 years ago, on the claim consisted of a trench, 50 feet long and 8 feet deep, cut across the quartz vein (see Plate 3). In 1942, Mr. G.E. Fielding, the present owner, cleaned out this trench and carried it to a depth of twelve feet. A smaller test pit has been sunk about 20 feet southeast of the main trench.

In 1946 the property was examined by Mr. J.J. Lyons who describes the main trench as follows: (see Plate III)-

"The upper three feet of the trench wall consist chiefly of a shattered barren-looking glassy quartz. This appears to be an 'overcapping'. It is cut by two strips or chimneys of massive sulphides, one near the eastern end of the trench, the other some 8 feet from the west end.

Below this overcapping the trench may be divided into four zones as follows:

Zone A. (East End)- a seven foot section of massive sulphides with a very minor amount of carbonate gangue. The sulphides appear to be mainly pyrrhotite.

Zone B. (East Centre)- a 10 feet horse of quartz similar to the 'overcap'. Near the contact with the sulphides to the east the quartz shows a little chalcopyrite mineralization to a depth of six inches. A band of actinolite-tremolite marks the contact with the carbonate zone to the west.

Zone C. (West Centre)- a 13 foot section of crystalline, grey carbonate, heavily mineralized with sulphides and sulpharsenides and showing minor inclusions of talc-chlorite schist. The outstanding sulpharsenide present is probably cobaltite. The more notable sulphides are chalcopyrite and nickeliferous pyrrhotite. A buff-white mineral, possibly scheelite, is also present.

Zone D. (West End)- a four-foot section of massive sulphides, similar to that at the east end, but with slightly greater amount of carbonate dispersed through it.

Two flat faults, practically horizontal, were observed at a depth of 6 feet and 9 feet. The upper one shows one-half to one inch of rusty weathering, pitted material with considerable amounts of sericite. This filling seems to come from the sulphide chimneys which cut the quartz. The lower fault traverses all four zones of the trench. It appears to be a channel of percolation of groundwater as considerable seepage was noted along it. The filling is about one-half inch of mud. Mr. Fielding mentioned that the values obtained below the mud seam were much better than above it."

Mr. Lyons shows, on a map accompanying his description of the trench, a further subdivision of the zones, by including an "intermediate zone" (see Plate III). This was described as a quartz carbonate-scheelite zone, and carries values in tungsten.

During the preliminary examination, lack of man-power prevented a thorough sampling. However, holes were drilled to a depth of about a foot in the floor, blasted, and twenty to twenty-five pounds of freshly-broken material were taken as samples. The carbonate zone was found to contain 2.47% cobalt and the intermediate zone 1.29% tungsten. These results warranted further development. Accordingly, the trench was further cleaned and sampled, and diamond drilling was carried out to determine the downward and lateral extent of the surface showing. A total of 1314 feet of drilling was completed in nine holes. The locations, depths and attitudes of these holes are given on Plate II. The drill logs are attached as appendix A. In only two holes, (1 and 7) were any indications of metallic minerals found, and none warranted assaying. In both cases the mineralization was chiefly pyrrhotite enclosed in narrow veins of glassy blue grey quartz.

PETROGRAPHY

"GREENSTONE" (Altered Diabase)

In the vicinity of claim S-4875 the diabase has been completely altered to a greenstone. Three thin sections (Nos. 1, 2 and 3) were cut for examination with the microscope.

Section No.I

Section No.1 is from diamond drill hole No.1 at a depth of 53 feet. This specimen is lighter in color than the ordinary greenstone and on a drill cut surface is almost white. No mafic minerals are identifiable in the hand specimen.

In thin section the rock shows 82% albite, 9% zoisite, 7% calcite, 2% tremolite and minor sericite. About two-thirds of the albite is in lath-like crystals resembling the ophitic texture of a diabase. Such albite is extensively twinned and is in general quite fresh in appearance, with only scattered flakes of an alteration product, probably sericite. The remainder of the albite is in irregular untwinned grains lying between and penetrating the lath-like crystals. This portion is evidently of secondary origin. Various extinction angles were measured to determine the calcity of the albite; $\perp X\ (Y \wedge 001) = -14^\circ$ nX and nY are both less than 1.537, with nZ about 1.537. On the untwinned variety $\perp Z\ (X \wedge 001) = 14^\circ$. The plagioclase is thus between An5 and An10. The albite is extensively shattered and cut by stringers of calcite, in part along cleavage cracks.

The zoisite stands out clearly due to its high relief. It is a colorless aggregate somewhat scaley in appearance and in places forms irregular masses with almost opaque cores. Elsewhere it is found along what appear to be solution channels. In no case is it sufficiently well crystallized to allow positive identification, so may consist in part, at least, of clinozoisite and epidote.

The tremolite occurs in elongated crystals lacking in well defined terminations. It retains a good pyroxene cleavage indicative of uralitisation. In thin section it is easily recognized by its moderate relief and intense blue and red second order interference colors.

Section No. 2

The specimen from which this section was cut is from the greenstone on claim S-4875. On a weathered surface the amphibole stands above the ground mass as greenish black knobs averaging about 1/8 inch in diameter. These show no crystal outline and cause the weathered surface to be much rougher than a freshly-broken surface. The ground mass is grey-white in color with shades of green and pink, presumably developed on the feldspar, which has weathered more rapidly than the amphibole. On a fresh surface the greenstone is dark green in color, and has a sugary appearance. Individual grains can be distinguished only with difficulty.

In thin section the mineral content is: albite 55%, tremolite-actinolite 30%, chlorite 12%, zoisite 2%, with magnetite and sericite making up the remaining 2%.

The plagioclase in section No.2 has about the same indices of refraction and extinction angles ($\perp Z\ (X \wedge 001) = 16^\circ$) as that in section No.1 (between An_5 and An_{10}). However, the appearance of the feldspar is quite different, in that the grains are anhedral and twinning is much less pronounced. It commonly occurs as irregular grains and also as a matrix for the remainder of the minerals. Sieve structure is common, with the inclusions consisting of small grains of calcite, tremolite, zoisite and a fine scaley alteration product, probably sericite. In many cases these are so abundant as to prevent the measurement of extinction angles. The albite shows less crushing than in section No.1, but a few fractures, filled with calcite or albite itself, were noted. In some areas, remnants of an original diabasic texture are identifiable.

The tremolite-actinolite is much more prominent in this section than in section No.1, but lacks the needle-like shape ; the grains are either shapeless or have well-developed prism faces but no regular terminations. The outer borders of many grains show faint pleochrism, in which Z is light green to light blue green, X and Y colorless to pale yellow.

The pleochroism indicates an increase in the iron content and a gradation from tremolite into actinolite. A small amount of the mafic mineral is pleochroic in brownish tones darker than common actinolite. In some of these grains amphibole cleavage is well developed, and it may be that a portion of the amphibole is a variety of hornblende.

The chlorite is contained in both the feldspar and tremolite. In the tremolite it is commonly oriented with cleavage flakes parallel to the pseudomorphous pyroxene cleavage. Elsewhere it occurs in small diamond shaped grains, both singly or in irregular clusters throughout the rock. This chlorite is a colorless variety, with pleochroism faint or lacking; under crossed nicols it has a low birefringence, and often shows a well defined ultra-blue interference color. The axial plane is parallel or nearly parallel to the elongation and cleavage. The elongation is negative and the chlorite is biaxial ( ).

The zoisite occurs in small grains and clusters, similar to its occurrence in Section No.1. Magnetite occurs as a few isolated grains, lacking crystal outline.

Sericite occurs in the albite as fine scales, in places so abundant as to mask the feldspar completely, and under crossed nicols shows the characteristic interference colours.

Section No.3

On the weathered surface this specimen is similar to No. 2. On a fresh surface it is seen to be somewhat more coarse-grained with stubby, 1/8-inch crystals of dark green amphibole. The groundmass is grey-green in color and the rock lacks the sugary appearance of more finely grained specimens such as No.2.

The thin section cut from this specimen has the composition: albite 50%, tremolite 40%, zoisite 5%, chlorite 4%, calcite 1% and a small amount of sericite.

Both in composition and texture this specimen resembles specimen No.2, but suggestions of an original ophitic texture are almost completely absent. The feldspar lacks crystal outline, contains sericite, and is seldom twinned. In places it is fractured and the fractures are filled with calcite and albite.

The actinolite-tremolite is coarser than in the other sections but otherwise quite similar. In places it appears interstitial to the albite, but in other places clearly penetrates it; again it may be replaced by feldspar, both along cleavage planes and around its margins.

The accessory minerals are as in the other sections.

VEIN

Section No.4

This slide was cut to show a more or less sharp contact between quartz and tremolite as found in drill hole No.1 (between 51.9 feet and 53.6 feet).

The quartz is massive, clear, relatively free from inclusions, fresh in appearance and partially replaces the tremolite. It is in places cut by small veinlets of calcite.

The tremolite is in fine needle-like crystals, imbedded in a groundmass composed essentially of calcite. It is similar to the tremolite-actinolite in the greenstone except that it lacks pleochroism and has a more pronounced acicular habit.

Chlorite occurs in close association with the tremolite, and in places is apparently pseudomorphous after it. The chlorite grains are too small to permit accurate determination.

Section No.5

This section was cut from the carbonate zone (C) of pit No.1. In the hand specimen it is pale green to grey white in color, apparently consisting mostly of tremolite and calcite. Some of the latter is a pale brown and effervesces strongly with dilute HCl. This rock contains abundant cobaltite in crystals up to ½" in diameter. Quartz and chlorite can be distinguished in isolated grains, and fine irregular flakes of graphite occur disseminated throughout the rock, some grains being large enough to be identified megascopically.

In thin section little information could be obtained. The section merely shows a fine-grained scaly aggregate, which appears to consist largely of a groundmass of calcite with imbedded tremolite, sericite and possibly talc.

Section No.6

This specimen was also taken from the carbonate zone of pit No.1. In hand specimen it is light grey-green to pale grey in color and shows grains of quartz from 1/16 inch to 1/8 inch across imbedded in a tremolite-calcite ground mass.

The thin section has a mineral composition as follows: Quartz 24%, calcite 56%, tremolite 4%, with the remainder of the section an unidentifiable scaley aggregate.

The quartz occurs in irregular disseminated grains generally free from inclusions, and shows marked strain effects. A pseudo-cleavage was observed in many of these quartz grains, all of which have a common orientation. It is obvious that the quartz has been shattered, veined and extensively replaced by the calcite.

The calcite has likewise extensively replaced the tremolite, which now exists only as small corroded needle-like crystals throughout much of the section. Elsewhere the tremolite is more dominant and occurs in well-defined radiating masses. It is lacking in pleochroism so probably contains less iron than the tremolite-actinolite in the greenstone.

Section No.7

Much of this specimen, which was also taken from the carbonate zone, is of well-crystallized grey to grey-white carbonate. In the hand specimen one small crystal of talc was identified. The remainder is a dense scaley aggregate, pale grey-green to grey-white in color. In thin section this is seen to consist of 80 to 85% carbonate, invading and enclosing a mixture of fine grained sericite with possibly some talc.

The sericite, although generally fine-grained, is in places sufficiently coarse to permit identification by its moderate relief, brilliant interference colors and excellent basal cleavage. Much of the sericite has calcite deposited along its cleavage planes. Small irregular flakes of graphite are sparsely scattered through the section and one small crystal of feldspar showing albite twinning was noted.

Section No.8

In physical appearance this hand specimen represents a transition between the carbonate zone, which has a high content of calcite and tremolite, and the so-called intermediate zone which carries the reported tungsten values. It is a light grey white in color and contains abundant clear colorless quartz in a massive fine grained matrix.

The thin section shows a highly altered aggregate of saussuritic material consisting of zoisite and clinozoisite (with some epidote) 40%, calcite 5%, quartz 25%, and the remainder altered albite feldspar.

Quartz occurs both in irregular fragments, frequently subangular, and as small veinlets cutting the other minerals. In the former case the fragments are apparently residuals of brecciation and possibly some replacement of quartz. In no case was quartz found in a state that would indicate a primary origin (e.g. interstitial to feldspar). It is clear and devoid of inclusions.

The zoisite and clinozoisite are in small rounded grains which occur both singly and in clusters, in places having a common optical orientation, apparently pseudomorphous after plagioclase. In many cases the clusters show interference colors ranging from a Berlin blue on the outer fringes to high second order colors in the interior. At least the Berlin blue variety is optically positive and has a large optic axial angle. The common association of the zoisite and clinozoisite with albite suggests their formation from plagioclase.

The albite contains a large proportion of a scaley colorless alteration product showing moderate to high relief, high birefringence (3rd order) and assumed to be sericite.

The calcite occurs mainly along small solution channels. Like the quartz it lacks inclusions.

Section No.9

This section was obtained from the "intermediate zone", a quartz-carbonate-scheelite-feldspar rock. In the hand specimen the rock is a light grey green in color, with a faint mottled appearance due to coarse, corroded phenocrysts of plagioclase.

Quartz can be easily distinguished megascopically, as it is found in irregular clear masses up to ¼" in diameter. The hand specimen was hand-picked for its scheelite content, which is easily visible, occurring in large, irregular, lustrous masses, almost colorless and showing good cleavage. However, due to its erratic distribution none was found in the thin section.

The mineral content of the section is plagioclase 60%, quartz 30%, clinozoisite, epidote and possibly some zoisite 8%, calcite 2%, with a minor amount of orthoclase and sericite, and possibly some fine grained secondary albite.

The plagioclase is a bytownite. The calcium content was determined by several different methods, all of which gave general agreement (An 76 - An 82). It has moderate relief and low birefringence. 2V is large (80° - 90°), and the optic sign is negative.

The following determinations of the plagioclase were made:

(a) Determination of nZ by immersion in oils showed nZ 1.574 (An 79 as a minimum).

(b) On a section $\perp Z$, $(X \wedge 001) = 42^\circ$ (An 76).

(c) On a section $\perp$ to optic axis B, $(Ax.Pl. \wedge 001) = 22^{c}$ (An 82).

The average of these methods is An 79.

One or two of the bytownite grains show albite twinning but carlsbad twinning is more common. The bytownite is in large crystals which in many instances retains prismatic faces, but are more often extensively corroded and replaced by a fine intergrowth of quartz, orthoclase, and possibly some secondary albite. Replacement has also proceeded noticeably along the cleavage cracks. Still other grains have been altered to give a high sericite content.

The quartz in the section has two distinct modes of occurrence, firstly as irregular masses up to 3/8" in diameter, and secondly as small rounded grains in an intergrowth with orthoclase and perhaps some albite, replacing as well as peociloblastic within the plagioclase. These inclusions of quartz in plagioclase resemble myrmekite. In both cases the quartz is clear and free of inclusions.

Small amounts of saussuritic material occur throughout the section, either as small single grains or as shapeless aggregates, within which clinozoisite is easily recognized by its deep Berlin blue interference color. It is non-pleochroic but is rarely found sufficiently well developed to allow the measurement of extinction angles; in one case $\perp 010\ (Z \wedge 001) = 18^\circ$. The epidote generally forms the core of a mass of clinozoisite and epidote, and, unlike clinozoisite, it has interference colors reaching high second order but shows no Berlin blue under crossed nicols. Cleavage flakes of epidote show on a section $\perp 010\ (X \wedge c) = 3^\circ$.

The clinozoisite and epidote often show optical continuity, but the boundary between the two is sharp. Some muscovite is intergrown with the clinozoisite and epidote in such an orientation as to suggest growth along original cleavage planes of the feldspar.

The small amount of calcite present is mainly concentrated along solution channels.

GENERAL

From a study of its mineral composition and texture, it would seem reasonable to assume that the greenstone was formed from the diabase dikes described by Quirke.

Quirke described three systems of these dikes, a quartz diabase, a diabase, and an olivine diabase, the mineral compositions of which are as follows:

1. Quartz diabase: oligoclase-albite 40%, quartz 20%, orthoclase 15%, altered hornblende 2%, with accessory andesine, microcline, calcite, ferrite, zoisite, chlorite, sericite and kaolin.
2. Diabase: plagioclase (albite to labradorite) 25 to 65%, secondary hornblende 70% to 20%, with accessory magnetite, biotite and apatite.
3. Olivine diabase: labradorite 70%, olivine 15%, augite, less than 10%, with accessory biotite, magnetite and apatite.

Further alteration of the quartz diabase would almost certainly result in a rock containing a considerable amount of quartz. Neither the albitization of the plagioclase nor the alteration from pyroxene to amphibole would appreciably lower the quartz content, and there is certainly no evidence to suggest a leaching of such a quantity of quartz (20%) by hydrothermal solutions. Therefore, since the greenstone on the Fielding property contains no quartz, it is assumed that it has not been formed by the alteration of quartz diabase.

In the case of the olivine diabase hydrothermal alteration of olivine would almost certainly produce some magnetite or serpentine as a by-product. Only a negligable amount of magnetite was found and no serpentine. Therefore, in lieu of further evidence, it can be assumed that the greenstone is the altered equivalent of what Quirke calls simply "diabase".

Quirke describes these diabase sills and dikes as Keweenawan in age. Such late Precambrian intrusions in the Canadian shield are generally comparatively fresh. Consequently, it might be suspected that the diabase on the Fielding property is pre-Keweenawan, possibly Matachewan, although work in nearby areas supports Quirke's classification.

Collins, W.H. "North Shore of Lake Huron", G.S.C. Mem. 1943.

Collins, W.H. and Quirke, T.T. Geol. Survey of Canada Map 291A Espanola Sheet 1938.

In any case, the metamorphic products may be regarded as having their origin in a diabase of Precambrian age, which was followed by at least one period of minor intrusion in this area (the olivine diabase). To the east and to the west of the Espanola map area Collins has mapped Killarney age granite, which is older than the olivine diabase but younger than other diabases.

The plagioclase of the diabase has been saussuritized to an albite-epidote-zoisite-clinozoisite mixture. The actinolite-tremolite is undoubtedly a product of uratilisation of the pyroxene. The chlorite is probably an early stage alteration product of the pyroxene, but a minor amount is associated with the albite so may be a hydrothermal alteration product of plagioclase. The sericite is an alteration product of the albite.

Although the chlorite-epidote-calcite content of the greenstone decreases with the increase of tremolite, it is evident that most of the tremolite was formed from pyroxene rather than from these alteration products, since it not only pseudomorphs the pyroxene but has pleochroic and adsorptive borders common in uralite.

Barlow, A.E. "Origin, Geological Relationship and Composition of the Nickel and Copper Deposits of the Sudbury Mining District, Ont. Can." G.S.C. Pub. 873, 1904.

Since albite crystals are shattered and intruded by small carbonate veinlets, the greenstone must have undergone crushing previous to or possibly contemporaneous with the injection of the vein material.

The calcite in part may have been released during the alteration of the mafic constituents of the original diabase, but its abundance in the actual vein and its customary habit of intruding the crushed greenstone as small veinlets, would indicate that the bulk of it was introduced.

In the carbonate zone, the tremolite-calcite ground mass is described by Mr. Lyons as enclosing and replacing the shattered quartz, but as seen in Section No.2, at least the later phases of the quartz are replacing some of the tremolite.

The presence of a calcic plagioclase in the so-called intermediate zone, presents a genetic problem. The quartz-orthoclase content suggest the introduction of hydrothermal solutions, and the presence of scheelite also suggests an introduction of solutions at high temperatures and possibly from an acidic magma. The "tear-drops" of quartz enclosed in the bytownite suggests that the feldspar may have been formed from a less calcic variety with contemporaneous release of the quartz. The restriction of bytownite to the intermediate zone cannot be readily explained.

N.L. Wilson, in describing a similar occurrence of calcic-feldspar in veins at Montauban-Les-Mines, Que., ascribes their origin to the high calcium content of hydrothermal solutions.

Another point requiring explanation is the fact that the bytownite has not been albitized, whereas in the remainder of the sections studied the feldspar is entirely albite. This would appear to suggest that albitization preceded the hydrothermal injection of quartz, orthoclase, and scheelite. As will

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Wilson, N.L. "Metamorphism of the Orijärvi Type", Doctorate Thesis, McGill University, 1939.

MINERAGRAPHY

A number of sections were cut from the sulphide and sulpharsenide samples collected at the Fielding Property. These sections were chosen to give, as nearly as possible, representatives of the various metallic mineral associations, as well as specimens from various parts of the deposit. The majority were obtained from the main trench (pit No.1), and a few samples were taken from diamond drill cores.

The study of the mineral sections was carried out in an attempt to determine the metallic minerals present, their mode of occurrence, relationship to one another, and their relation to the gangue minerals. For the identification of the component minerals, procedures outlined by M.N. Short and Ellis Thomson were followed.

Short, M.N. "A Microscopic Determination of the Ore Minerals", U.S.G.S., Bull. 914.

Thomson, Ellis, "A Qualitative and Quantitative Determination of the Ores at Cobalt Ont." Econ. Geo. Vol.25, 1930.

As has already been noted in the general description of the property, the main showing is in Pit No.1, (Plate III) where the mineralization is of two distinct types, and allows the vein to be easily divided into zones. The two main zones are the massive sulphide zone and the cobaltite-carbonate-tremolite zone. Although the dividing line between these zones in places may be fairly sharp, hand specimens show gradation from one to the other

The massive sulphide zone consists essentially of pyrrhotite, with minor amounts of chalcopyrite and cobaltite. The pyrrhotite is a pale brass color on the fresh surface. The weathered surface is a deep blue black to dark brown in color, due to an iridescent tarnish. Many of the specimens collected are almost wholly sulphide. The gangue is chiefly dark grey carbonate-tremolite rock. Chlorite and talc are present in small amounts. The carbonate is either irregular in shape due to replacement by pyrrhotite or in angular breccia-like fragments.

Assay values for samples from the massive sulphide zone are as follows:

		Au OZ/ton	Ag OZ/ton	Ni %	Cu %	Co %
I.	East end of floor (massive sulphides, chiefly pyrrhotite)	0.02	0.16	0.57	0.44	--
II.	West end of floor (massive sulphide, mostly pyrrhotite with some carbonate)	0.02	0.06	0.59	0.20	0.41
III.	(a) Massive Sulphide	---	---	0.53	---	0.27
	(b) Massive Sulphide	---	---	0.66	---	Tr.

(---) not determined.

The carbonate zone consists mainly of well developed cobaltite crystals in a ground mass of light grey carbonate and pale green tremolite, with some dark green chlorite and fine flakes of talc and sericite.

Results of assays of samples from the cobaltite-carbonate-tremolite zone are as follows:

		Pt Oz/ton	Au Oz/ton	Ag Oz/ton	Ni %	Cu %	Co %	W %
IV.	(a) West centre floor: carbonate, quartz, sulphides and arsenides	0.02	0.03	0.08	0.89	0.34	2.47	0.02
V.	(a) Carbonate-tremolite zone	---	---	Nil	0.43	---	1.75	---
	(b) " "	---	---	Nil	---	---	2.89	---
VI.	(a) " "	---	---	---	1.14	---	3.61	---
	(b) " "	---	---	---	---	---	3.76	---

The two zones above comprise the bulk of the metallic mineral showing, but the glassy quartz is cut by small veinlets of sulphides, and the greenstone in places has been replaced directly by cobaltite, löllingite, gersdorffite and, to a lesser extent, by ferberite.

The metallic minerals are generally fresh and unaltered. A few feet below the surface, weathering has been effective only along solution channels and has failed to effect the majority of the sulphides and sulpharsenides. The carbonate shows here and there an occasional rusty streak due to oxidation of the pyrrhotite, and similar narrow rusty bands separate fresh calcite and fresh pyrrhotite in some places.

The metallic minerals encountered during the study of various specimens are pyrrhotite, cobaltite, gersdorffite and chalcopyrite, with lesser amounts of polydymite, skutterudite, loellingite and ferberite.

PYRRHOTITE

Pyrrhotite occurs in varying proportions in all parts of the vein. It is easily distinguished in the polished specimens by its deep cream color and strong anisotropism. The anisotropism is in colors of cream yellow, pale orange yellow, grey and grey blue, depending upon the orientation. There is no tendency toward crystal outline, but rather it occurs as shapeless interlocking grains occasionally showing irregular twin lamellae. Although many grains show fracturing and shearing it has not been broken to the same extent as the cobaltite.

Many of the small fractures in the pyrrhotite are filled with small stringers of quartz and calcite, (Plate V) showing that minor amounts of gangue material were deposited later than the period of maximum pyrrhotite deposition. Numerous small inclusions often give the pyrrhotite a marked pitted appearance. Microchemical tests indicate the presence of nickel and small amounts of copper in much of the pyrrhotite.

In the various sections examined the pyrrhotite shows the following associations:

(1) In the massive sulphide zone it cuts and replaces medium grey calcite. Fragments of calcite in the pyrrhotite may be corroded residuals, or sharp angular grains indicating little replacement.

(2) In the carbonate zone it cuts the light grey carbonate-tremolite gangue, and in numerous cases, is seen to cut large cobaltite crystals as small veinlets guided by fracturing, (Plate VI) indicating a period of brecciation between the deposition of these two minerals.

(3) It is also found as small veinlets cutting glassy quartz and obviously guided by fracturing. The pyrrhotite is often accompanied by chalcopyrite which forms boundaries of the veinlets. Small grains of cobaltite may also be present.

COBALTITE AND GERSDORFFITE

Cobaltite (CoA_sS) is the dominant sulpharsenide in the mineral association, but the nickel sulpharsenide, gersdorffite, is also present. In polished sections it is almost impossible to differentiate between the two save by microchemical tests. Their reflectivity, color, hardness, and reaction toward etch reagents are similar. Some isomorphous substitution of nickel in cobaltite, and cobalt in gersdorffite undoubtedly occurs.

The gersdorffite generally occurs massive, lacking crystal outline, whereas the cobaltite is markedly crystalline. However, the small grains and stringers of these two minerals cannot be differentiated. In the discussion on paragenesis and relation to other minerals, the information regarding the more common cobaltite is assumed to be applicable to the gersdorffite.

Cobaltite occurs mainly in the carbonate zone of pit No.1, and in lesser amounts in the other zones. In the carbonate zone it forms euhedral crystals up to ½ inch across. These are tin-white in color, in places with an iridescent tarnish. They are generally simple cubes, but octahedral and dodecahedral forms are present. Many of the smaller crystals show spinel twinning. The larger crystals are commonly shattered; on leaching with dilute HCl they tend to disintegrate as calcite fracture fillings are dissolved.

All etch reagents used except 1:1 HNO_3 show no effect on the cobaltite. The HNO_3 fumes produce a faint tarnish and the acid may or may not leave a differential brown stain, emphasizing scratches. Some crystals were subjected to prolonged etching in an effort to reveal zoning, but none was noted. Microchemical tests indicate a large nickel content in the cobaltite, and some tests showed the presence of copper.

The cobaltite occurs as follows:

(1) As noted above, it is the chief mineral in the carbonate zone of pit No.1 where assay values range up to 3.76% cobalt. The cobaltite apparently replaces the carbonate (Plate VII) but is in turn cut by small veinlets of calcite and quartz. Small veinlets of pyrrhotite and chalcopyrite also cut these larger crystals (Plates VI and XI).

(2) Small grains of cobaltite are found in veinlets cutting pyrrhotite.

(3) It forms the borders of pyrrhotite veinlets which cut and replace quartz (Plate VIII).

(4) Small isolated grains are found in massive pyrrhotite.

(5) It also replaces all minerals of the greenstone save tremolite, (as for gersdorffite, Plate IX). The borders between the cobaltite and greenstone minerals show the replacing cobaltite to be euhedral, evidencing its crystalloblastic force (Plate X). The replacement evidently takes place from the cobaltite outward into the gangue, as well as replacement outward from small centres along the border just inside the gangue minerals. The latter mode gives rise to numerous small crystals along the border zones.

(6) Angular fragments in the carbonate are evidently the result of crushing and brecciation with later recrystallization of the calcite.

(7) A small amount is intermixed with, and possibly replaces pyrrhotite as evidenced by concave boundaries of the pyrrhotite.

(8) In small veinlets it occurs with pyrrhotite and chalcopyrite cutting quartz.

The fact that the cobaltite crystals are generally fractured and cut by quartz, calcite, pyrrhotite and chalcopyrite (Plate XI) would indicate that it not only occurred early in the mineralization sequence but also that it preceded a period of minor movement along the zone. However, small amounts of cobaltite are found later than at least a portion of the pyrrhotite. Therefore, it seems probable that the cobaltite mineralization reach a maximum early in the sequence, but continued to near the end of the period.

CHALCOPYRITE

The only copper mineral present is chalcopyrite, (CuF_eS_2) which is generally associated with the pyrrhotite rather than the cobaltite. Only two assays were made for Cu, and these showed 0.34% and 0.20%. The chalcopyrite is easily distinguished in the polished specimens by its brassy yellow color. It is slightly anisotropic and has a much less pitted surface than the pyrrhotite. It is generally unaffected by the ordinary etch reagents, but some specimens show an even brown tarnish with KCN.

Chalcopyrite was noted to occur as follows:

(1) The majority of the chalcopyrite occurs along the borders between carbonate and pyrrhotite, (Plate XII) in bands up to 2 or 3 mm. wide.

(2) Irregular grains of chalcopyrite are commonly cut by small veinlets of pyrrhotite.

(3) Small replacement veinlets are found along fractures in quartz and carbonate. In these small veinlets it is often found associated with pyrrhotite and occasionally with cobaltite, showing that during some stage of the

mineralization cobaltite, chalcopyrite and pyrrhotite were deposited contemporaneously. In numerous small pyrrhotite-chalcopyrite veinlets cutting quartz, chalcopyrite occurs on the borders with the centre composed of pyrrhotite.

(4) Small veinlets filling tiny fractures in cobaltite crystals are found.

The bulk of the chalcopyrite occurs along contacts between carbonate and pyrrhotite, and is apparently pre-pyrrhotite, but a certain amount has definitely been contemporaneous in deposition with pyrrhotite and cobaltite. It seems most likely that the chalcopyrite was deposited during the intermediate stages of mineralization. The fact that it is completely unfractured may indicate a post-movement origin. On the other hand, its soft, more ductile nature may have withstood the small amount of shearing force which sufficed to fracture the more brittle minerals. Since the pyrrhotite has suffered a slight shearing the latter alternative seems more probable.

LOELLINGITE

No loellingite ($FeAs_2$) was found in the specimens taken from the main trench, but a section taken from drill hole No.1 (51.9 ft. - 53.6 ft.) shows a small area composed of an intimate mixture of gersdorffite and a mineral believed to be loellingite. Where the magnification is less than X100 the two minerals cannot be distinguished one from the other, but under higher magnifications the loellingite is seen to be a whiter shade.

Unlike the gersdorffite, the loellingite shows fairly strong anisotropism in colors of light yellow and pale blue, and commonly shows narrow twin lamellae; it reacts more strongly with HNO_3 which causes an iridescent tarnish. It is negative to other etch reagents.

The loellingite is generally too finely grained to permit microchemical tests, however, one grain, large enough to be removed, yielded positive reactions for arsenic and iron.

The intimate mixture of the two minerals in this section suggests contemporaneous deposition. Both are replacing all the greenstone minerals except tremolite (Plates IX and X).

POLYDYMITE

Careful examination of well-polished pyrrhotite revealed the presence of small needle-like inclusions of polydymite ($NiAs_2$) (Plate XIII). These are oriented parallel to the cleavage or parting in the pyrrhotite. They are much whiter than the pyrrhotite but of the same order of hardness. On etching the specimens with 1:1 HNO_3 the polydymite needles turn a deep brown color; other etch reagents have no effect.

The occurrence in parallel positions along cleavage or parting planes may be interpreted as either exsolution or replacement along the parting. However, the low nickel content of the pyrrhotite, together with the irregular outline of the needles as viewed under high magnification suggest that replacement is more probable.

According to Short, true polydymite is rare and most reported occurrences have proved to be violarite, $(NiFe)_3S_4$. The needles here found may be too small to show the diagnostic violet tinge of violarite, a mineral that might be expected to occur in pyrrhotite, an iron rich host.

FERBERITE

Ferberite ($FeWO_4$) was found in only one specimen, which was also rich in loellingite. It occurs in small grains, generally in the greenstone, but occasionally enclosed in massive sulpharsenides (Plate XIV). In places it forms small laths but more commonly is in shapeless or elongated masses apparently deposited along cleavage planes of the greenstone minerals. Small stringers of the arsenical minerals cut the grains of ferberite, indicating that the tungsten minerals were deposited during the early stages of mineralization. The relation of the ferberite to the scheelite is not known

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Short, M.N. "Microscopic Determination of the Ore Minerals" U.S.G.S. Bull. 914, pp. 123.

but they are presumably of contemporaneous formation. Since the ferberite occurs only in the metallic minerals or in the diabase its relation to the calcite and quartz is also unknown.

GANGUE MINERALS

The gangue minerals of the vein consist mainly of calcite, with quartz, tremolite, the greenstone itself, and small quantities of chlorite, sericite, and talc.

A large vein of massive clear glassy quartz, which carries low values, but appears extensively shattered, cuts the greenstone. Small veinlets of sulphides cut this quartz along the fractures. The quartz associated with the carbonate, tremolite, and massive sulphide zone has a grey blue milky appearance and is probably later than the barren glassy quartz. The carbonate-tremolite zone has already been described to some extent in the section on petrography. The metallic minerals are found mainly in carbonate rather than in quartz. Many angular carbonate fragments are enclosed in the pyrrhotite indicating brecciation between the period of calcite deposition and pyrrhotite mineralization.

Although the bulk of the carbonate and quartz were deposited before the metallic minerals, small veinlets of quartz and calcite cut the sulphides and sulpharsenides, indicating that they were being deposited, at least in small amounts, after or during the deposition of the metallics. However, both the silica and calcite in these veinlets could be the result of leaching of previously deposited material and redeposition from the mineralizing solutions.

The well developed crystals of tremolite enclosed in sulpharsenides give evidence of that fact that metamorphism preceded the introduction of the metallic minerals.

NICKEL CONTENT

Polydymite (or violarite) and gersdorffite are the only true nickel minerals found on the property. Nickel assays range from 0.43% to 1.14% and microchemical tests show appreciable nickel in both the cobaltite and pyrrhotite.

If the nickel content is plotted against the cobalt content (Plate IV), it can be seen that even in the massive sulphides (chiefly pyrrhotite), which assayed only a trace of cobalt, 0.66% Ni is present. Since the sulphide zone contains Less than 25% gangue, it can be assumed that the pyrrhotite arries about 0.5% nickel. How much of this is present as olydymite is not known. In general the nickel content varies ith the cobalt, and one sample, containing 3.61% cobalt, ssayed 1.14 nickel. Since cobaltite carries only a small mount (maximum reported 3.20%) of nickel, about one third ..14/3.61) of the sulpharsenide is probably gersdorffite.

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alache, Berman and Frondel, "Dana's System of Mineralogy", 7th Ed., Vol.1.

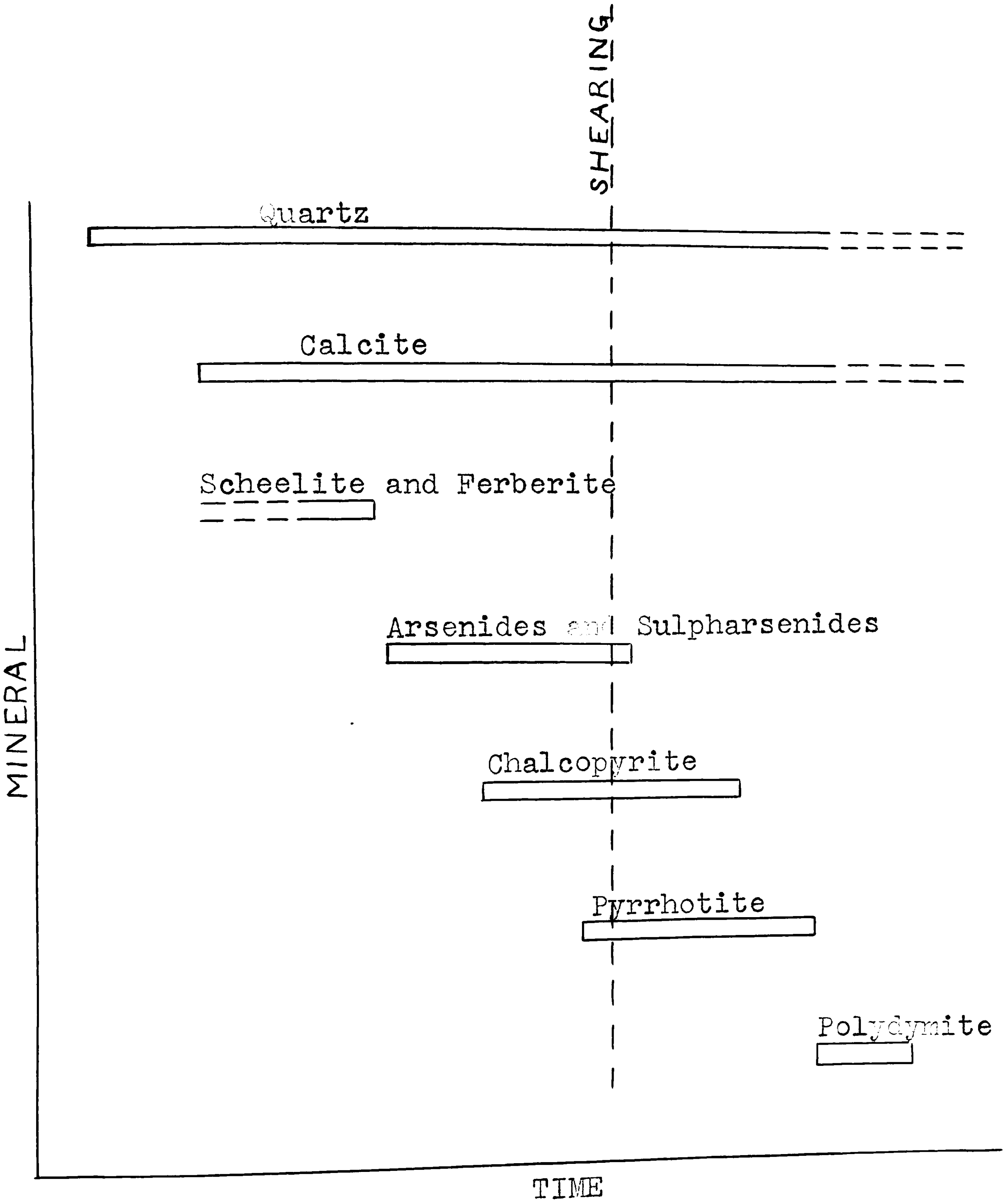
PARAGENESIS

The study of the polished specimens reveals that the deposition of any particular mineral present was not confined to any one phase of the mineralization. Instead, contemporaneous deposition was taking place, but with a wide variation in the relative quantities deposited. Therefore, rather than assigning each mineral an isolated position in the sequence of deposition, points of maximum relative deposition are emphasized.

The showing in pit No.1 lies within a large quartz vein which is generally barren, but is in places extensively shattered and carries abundant calcite, tremolite and metallic minerals. This leads to the conclusion that the early stages of the vein formation was characterized by large quantities of essentially barren quartz. Small stringers of quartz also cut the latest of the metallic minerals, and show that quartz deposition continued until the final stages of vein formation.

The next phase of mineralization is believed to have been chiefly calcite. The large number of angular fragments enclosed in the massive pyrrhotite leaves little doubt that considerable calcite was formed prior to deposition of the pyrrhotite. The relation of the calcite to the sulpharsenides and arsenides is less certain, and indeed, has proved a point of contention in other similar deposits of

Fig.I



Graph showing periods of mineral deposition.

Ontario. The fact that the cobaltite overlapped the pyrrhotite (which is known to be largely post-calcite), places the calcite deposition at least as early as the sulpharsenides. Cobaltite in places replaces calcite along cleavage planes, and is largely confined to the carbonate gangue, which may have been instrumental in its deposition. The fact that the carbonate is easily replaced, allows ample opportunity for solutions to circulate along cleavage planes and has a low crystalloblastic rank, may account for the numerous large well formed crystals found in it, as compared to the smaller, more irregular grains found in the quartz and greenstone.

On the other hand, the small veinlets of calcite and quartz which cut the metallic minerals, proves that calcite deposition took place until near the end stages of mineralization. The late calcite may represent either introduced material or the result of solution and redeposition of early calcite.

The earliest metallic mineral is the ferberite. The resence of small laths and irregular grains of the tungsten mineral enclosed in massive sulpharsenides show it to be earlier than these minerals. Proof of this can be seen in small einlets of cobaltite cutting ferberite. The relation of the erberite to the scheelite is not known with certainty but he deposition of the two tungsten minerals is assumed to be ontemporaneous.

The maximum deposition of the arsenides preceded he deposition of the sulphides. Numerous crushed crystals f cobaltite have their fractures sealed by small stringers f chalcopyrite and pyrrhotite (Plates VI, XI), indicating that ot only were the arsenides deposited early in the sequence, ut that some movement along the zone intervened between the ajor sulpharsenide and sulphide periods of deposition. Narrow orders of cobaltite (Plate VIII) on pyrrhotite veinlets cutting uartz show cobaltite earlier than pyrrhotite, but small einlets, consisting of chalcopyrite, pyrrhotite and cobaltite how an overlapping deposition of these minerals. The intimate ixture of the loellingite and gersderffite indicate imultaneous formation.

Skutterudite was found in only one section. In this ection a tiny veinlet abutted against and followed along the ide of a large cobaltite crystal suggesting a later origin. therwise, nothing is known of its time of deposition, but it robably was formed early with the bulk of the arsenides and ulpharsenides.

The fact that a large proportion of the chalcopyrite s found coating angular calcite fragments, and is in turn oated by pyrrhotite, indicates that the majority of the chalcoyrite preceded the pyrrhotite, but as stated before, an overapping is noted.

The pyrrhotite is the latest of the main constituents, ut is followed by the polydymite, which is formed either by x-solution from the pyrrhotite or by replacement of it.

COBALT-NICKEL DEPOSITS OF THE WORLD

Deposits of cobalt-nickel arsenides are world wide in their distribution. The known deposits show a remarkable consistency in their mineral content, but the proportions of the various minerals vary through wide extremes. The widespread similarity suggests that more than local factors affect their character, and assignsthem a special place in the broad scheme of ore-deposit classification. Any discussion on the genesis of the vein on the property here concerned would be incomplete without reference to similar deposits elsewhere. Consequently a brief outline of several cobalt deposits of the world is presented with special emphasis being placed on the silver-cobalt-nickel arsenide type.

ONTARIO DEPOSITS

The silver-cobalt-nickel type of vein occurs sporadically over a wide area of Ontario North of Lake Huron. Deposits occur from Elk Lake on the north to Lake Huron on the south, and from the Quebec border on the east to Thessalon on the west, an area of several thousand square miles. If the silver deposits of Silver Islet be included, the area is greatly increased.

The main production of cobalt and silver has come from the Cobalt district, where rich veins were discovered

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Lindgren, W. "Mineral Deposits" 1933.

in 1903. The oldest rocks in the Cobalt District are of Kewatin age. They are a highly folded and contorted series of basic lavas, greenstones and schists, with accompanying cherty sediments. Some 300 feet of conglomerate and greywacke of the Cobalt series are comparatively flat-lying on top of the Kewatin.

The Cobalt and Kewatin rocks have been cut by a sill of Nipissing diabase up to 1250 feet thick. The composition of the diabase sill is fairly constant at Cobalt, but extreme variations are noted in outlying mining camps. The area is cut by several faults such as the Cobalt and Kerr Lake faults. These are of the reverse type and dip southeast, with displacements up to 500 feet.

The ore lies in short vertical fissures either in the diabase or in the conglomerate, as well as along fault zones. Most of the veins are short and narrow, depths of over 300 feet being exceptional. Some of the ore comes from the upper contact of the diabase, and some below. The ore minerals are mainly native silver, dycrasite, argentite, pyrargyrite, smaltite, niccolite, and cobaltite. The paragenesis of the ore and gangue minerals has been a subject of much dispute.

Miller, W.G. Ont. Bureau of Mines Report XIX, Pt.II, 1910.

The general concensus of opinion seems to be that the calcite gangue was deposited first, followed by the sulpharsenides of nickel and cobalt and finally by the silver minerals. Many early authors believed the silver to be largely due to secondary enrichment. Bastin believes silver is late in the sequence of mineralization, but partly contemporaneous with the arsenides, as shown by inclusions and incipient crystals of silver in the arsenides. A detailed study of the ore was carried out by Thomson, who believes the paragenesis to be as follows:

1.	Arsenides and Sulpharsenides	A-	Diarsenides, triarsenides and sulpharsenides of Co and Ni	a) <u>Cubic</u> Smaltite Chloanthite Skutterudite
				b) <u>Cubic</u> cobaltite gersdorffite
				c) <u>Orthorhombic</u> Safflorite rammelsbergite loellingite

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Young, J.W. "A Quantitative Study of the Ores at Cobalt Ont." Econ. Geol. Vol. 26 P. 112-118, 1931.

Bastin, E.S. "Significant Mineralogical Relation in Silver Ores of Cobalt Ont." Econ. Geol. Vol.12, 1917, pp. 219-236.

Thomson, E. "A Qualitative and Quantitative Determination of the Ores at Cobalt Ont." Econ.Geol. Vol.25, 1930.

B- Sulpharsenides and sulphides of iron	arsenopyrite pyrite
C- Monoarsenides and monoantimonides	niccolite breithauptite

11. Calcite Gangue-

III. Silver and bismuth minerals -

IV. Calcite

V. Sulphides of lead, zinc, copper, galena, pyrrhotite, marcasite, tetrahedrite and quartz.

VI. Sulpho-salts such as pyrargyrite, stephanite and later silver.

Thomson has the support of some other authors in placing calcite after the arsenides in the order of deposition.

The occurrences in the Gowganda mining camp are similar to those of Cobalt. The veins are closely associated with a sill of Nipissing Diabase. The relation of the Gowganda sill to the Cobalt sill is not known since an erosion gap separates them. Many of the veins in this area are in the Nipissing diabase whereas at Cobalt they are mainly in onglomerate. An interesting feature of the area is the resence of "aplite" or acidic dikes, many of which fill

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Miller, W.G. "Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming". O.B.M. 19th Report Pt.II, 1910.

Miller, W.G. "Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming". Ont. Bur. of Mines 19th Report, Part II, 1910.

ractures, possibly cooling cracks, in the diabase. In the lannigan Lake area these dikes have been split open and alcite, smaltite, niccolite, silver, etc., deposited in the pening. These acidic dikes will be more fully discussed ater.

iller, W.G., "Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming" Ont. Bur. of Mines 19th Report, Pt. II, 1910.

In the South Lorraine District the Kewatin complex s cut by Lorraine granite, prior to the deposition of uronian sediments. Otherwise the geology is similar to the obalt area. The veins are in Nipissing diabase and in ewatin rocks. The ore minerals are mainly smaltite, niccolite nd native silver.

SHINING TREE SILVER AREA

iller, W.G. "Cobalt-Nickel Arsenides and Silver Deposits of Temiskaming". Ont. Bur. of Mines 19th Report, Part II, 1910.

The Shining Tree Silver Area is in the Leonard Township, District of Temiskaming, Ontario. The country rock consists f Kewatin greenstone and iron formation overlain by Cobalt onglomerate, quartzite and slate. The Kewatin and Cobalt ocks are cut by dikes of diabasic and gabbroid types. The iabase is in turn cut by numerous "aplite" dikes. The veins re, for the most part, found cutting Nipissing diabase. The ineralization has followed narrow vertical fractures in the iabase, the width rarely exceeding a few inches. The minerals re chalcopyrite, smaltite, niccolite, bismuth, galena and ative silver in a gangue of calcite and quartz.

KERR CLAIM OTTER TOWNSHIP

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iller, W.G. Ont. Bur. Mines Report XIX, Pt.II, 1910.

A similar type of mineralization is found on the err claim, Otter Township, which is near Thessalon, about 00 miles west of Espanola. This showing is said to be related o a quartz diabase which has been altered to a uralite-aussurite rock similar to the greenstone on the Fielding roperty. The mineralization is mostly native silver, some obalt, and native bismuth. On both sides of the mineralized ortion of the vein is a layer of quartz, giving a comb tructure.

GREAT BEAR LAKE

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idd, D.F. "A Pitchblende-silver Deposit, Great Bear Lake, Canada". Econ. Geol. Vol.27, 1932, pp. 145-159.

In 1930 a pitchblende-silver deposit containing opper, cobalt and nickel was found on Labine Point, Great

Bear Lake. The country rock includes fine-grained sedimentary rocks, volcanic agglomerate, and feldspar porphyry sills. These have all been intruded and metamorphosed by granite. Younger than all these is a 200 foot sill having a composition close to a quartz norite. These rocks have been shattered and sheared along three separate zones, which have acted as loci of deposition.

The minerals present include pitchblende, arsenopyrite, pyrite, tetrahedrite, sphalerite, bornite, chalcopyrite, galena, cobalt-nickel arsenides, native bismuth, and native silver. The mineralization was originally considered to be related to the granite but is now definitely known to be later than this but older than the sill.

UNITED STATES DEPOSITS

The production of cobalt in the United States is mall, and deposits similar to the Cobalt Ontario deposits are ew. Perhaps the most comparable area is around Bullards Peak, New Mexico, with the adjacent Mexican deposits at Batopilas.

At Batopilas the ore is in andesite or diorite

Jolliffe, A.W. Personal Communication.

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reiger, P. "Primary Native Silver Ores at Batopilas, Mexico and Bullards Peak, New Mexico". Amer. Miner. Vol. 20 pp. 715-723.

which has been cut by coarse grained granite. The deposits have a deep seated origin and characteristically carry nickel and cobalt arsenides. The gangue is calcite with minor quartz and barite. Kreiger believes the mineralization is associated with the granite. The cobalt-nickel arsenides were formed early and followed by silver minerals and native silver. Both the textures and mineral composition at Bullards Peak resemble those at Cobalt Ontario.

In the Monte Cristo Mine at Wickenburg, Arizona, nickel and cobalt minerals preceded a silver mineralization. The ore is in a banded gneiss which has been intruded by pegmatite carrying tourmaline. Chalcopyrite is the main ore mineral, quartz is the dominant gangue, with a minor amount of calcite.

Cobalt has also been found in Missouri, where good cobaltite crystals are reported from Mine La Motte. The ore minerals lie in Cambrian and Silurian sediments. The ore minerals include galena and chalcopyrite, with nickel and cobalt minerals. Pyrite accompanies the ore minerals. The cobalt

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Bastin, E.S. "Primary Native Silver Ores Near Wickenburg Ariz. and their Bearing on the Genesis of Silver Ore at Cobalt Ont. U.S.G.S. Bull. 135, 1922, pp. 131-154.

"Nickel Deposits of the World", "Report of Royal Ontario Nickel Commission", 1917.

minerals lie near granite and granite porphyry contacts.

At the Gem Mine in Colorado nickel and cobalt sulpharsenides occur in a vein cutting hornblende schist. Some patchy native silver is present. The nickel content dominates the cobalt.

"Gem Mine, Freemont, Col." Thomas Charleton. Proc. Col. Sc. Soc. 189-93, pp. 420-241.

Cobalt is also found in North Carolina, Franklin, N.J., and at Chatham, Conn.

"Contributions to Mineralogy, No.54, North Carolina, Drums Farm" Amer. Jour. Science, 3rd Series, Vol.44, p. 384.

Whitney, H. "Metallic Wealth of the U.S." 1854 Chatham Conn. Cobalt Dep., p.497.

Holmes, R.J. "White Arsenides of Nickel and Cobalt occurring at Franklin, New Jersey". Abs. in Geo. Soc. of Amer. Bull. Vol.56, p. 1168.

EUROPEAN DEPOSITS

Numerous deposits of the type under study are found in Europe, although most of them have ceased to be of economic importance in cobalt production.

Erzegebirge Region of Germany and Czechoslovakia

Miller, W.G., Ont. Bur. Mines Rep. 19, Pt.D, 1913, pp. 213.
Bastin, E.S. and Hill, J.M. U.S.G.S. Prof. Paper 94, 1917, p.122.

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almar, K. "Erzegebirge of Germany and Czechoslovakia". Abs.
in "Nickel-Cobalt Native Silver Ore Type" by E.S.
Bastin, E.C. Geol. Vol.34, 1939, pp. 8-9.

The Erzegebirge region of Central Europe is one of the better known and more studied mining districts of the world. The district, which has been exploited since 1492, includes the mining camps of Schneeburg, Johanngeorgenstadt, Zwittermuhl, Joachimsthal, Geyer, Ehrenfriedersdorf, Annaberg, and Marienberg. The mineralization is essentially the same throughout the district.

The ore deposition has been mostly in Archaoozoic schists and gneisses which have been intruded by granite masses, although some are found in Cambrian-Silurian crystalline limestone. The granite shows considerable variation. Associated with it are dikes of lithium granite, quartz porphyry and granite porphyry. Less common are dikes of mafic composition such as diorite, minette and kersantite. Both classes of dikes are believed associated with the granite masses and preceded the period of mineralization.

The veins contain quartz in areas where quartz porphyry is common, but the gangue is generally calcite in limestone areas. The ore minerals include native silver, tetrahedrite, cassiterite, uraninite (pitchblende), niccolite, chloanthite, rammelsbergite, cobaltite, loellingite, sphalerite, chalcopyrite, galena, native arsenic, bornite, proustite, steinbergite, argentite and uranium mica. Pyrite is more common than pyrrhotite, and some marcasite occurs.

In all cases a definite sequence in deposition is noted as follows:

(1) Tin ores -

(2) Pyrite lead ores -

(3) Cobalt silver ores -

(4) Iron-manganese ores.

The cobalt-silver ores are the most common. Cobaltite is less common than chloanthite-smaltite. The veins are remarkably similar to Cobalt veins. There seems to be a general agreement on their relation to the granite intrusives, and lead-uranium ratios in the pitchblende suggest a late Paleozoic age.

Neir, A.O., Baxter, G.P. and Kelly, W.M. "Lead-Uranium Ratio in Pitchblende from St.Joaquimsthal." Report of the Committee on the Measurement of Geologic Time, p. 10, 1937-38.

Cornwall

Abs. in Bastin, E.S. "The Nickel-Cobalt-Native-Silver Ore Type", Econ. Geol. Vol. 34, p. 11, 1939.

The Cornwall district for years provided a large ortion of England's mineral wealth. Its similarity to the rzegebirge region is most striking.

In the Cornwall district sediments and minor igneous rocks were cut in late Carboniferous or post-Carboniferous times by granite stocks. Associated with and cutting the granite stock as well as the surrounding sediments are dikes of granite porphyry, quartz porphyry, micropegmatite and aplite. Minette dikes are present but less common.

Tin-copper veins carrying minor ferberite occur near the granite and are clearly related to it. Farther from the granite and less certainly associated with it are:
(1) Silver-lead ores occasionally carrying cobalt and nickel;
(2) iron-manganese veins. The zoning corresponds to the sequence of deposition at Erzegebirge. Pitchblende is also present but rare. The main gangue is calcite.

Other European Deposits

At Dobschau, in the Carpathian mountains of Hungary, veins occur in fractures in a diorite stock, but also cut post-diorite sediments. The veins carry chalcopyrite, smaltite, niccolite, loellingite, arsenopyrite and chloanthite. The veins can be related to no visible intrusive but the presence of tourmaline in the gangue suggests a connection with an acidic or intermediate magma rather than a basic magma.

Abs. in Bastin, E.S. "The Nickel-Cobalt-Native-Silver Ore Type", Econ. Geol. Vol.34, P. 15, 1939.

later eruptive, so the source of the minerals is not known.

At Talnnotry, Kirkcudbrightshire, niccolite-

"The Nickel-Cobalt Ore of Talnnotry, Kirkcudbrightshire". Inst. of Min. and Met. Trans. 37, pp. 178-182, 1928.

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cobaltite-pyrrhotite veins lie along a hornfels diorite contact. Since the ore occurs along a fault, and has intruded and altered the diorite more than the hornfels, it is believed to be of hydrothermal origin.

The Norwegian deposits at one time contributed

Miller, W.G. Ont. Bur. Mines, Vol.19, 1913, p.222.

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the major part of the world cobalt production, but are now relatively unimportant as far as their cobalt content is concerned. Around Skutterud the cobalt minerals are in fahlbands contained in mica schist, hornblende schist, and gneiss. The minerals include cobaltite, arsenopyrite, pyrrhotite, chalcopyrite and skutterudite. There is little nickel in the cobaltite. Diorite intrusives cut the ore. Dikes of coarse grained granite contain no ore but cut the diorite.

AFRICAN DEPOSITS

The cobalt produced in Northern Rhodesia, Belgian Congo and French Morocco constitutes the major portion of world supply.

In Northern Rhodesia the cobalt is produced as a by-product of copper. The ore minerals are mainly chalcocite, covellite, bornite and chalcopyrite, with a minor amount of cobalt produced from linnaeite. A small amount of pitchblende is present. The ore bodies are found in sandstone, dolomite, and shale which have been intruded by acidic and basic rocks, the basic being later. In the vicinity of the ore deposits dikes of pegmatite and acidic granite are found. Some copper is found in the pegmatite which indicates a genetic relation between the pegmatite and ore. A small amount of tourmaline is found with the ore at Mufulira, which again implies an acidic hydrothermal agent of deposition. It is noted that the linnaeite, which is older than the copper minerals, was deposited after the metamorphism. The ore shows a remarkable tendency to follow specific beds. Only small amounts of calcite and quartz gangue were introduced.

Bateman, A.M. "Ores of the Northern Rhodesian Copper Belt". Econ. Geol. Vol.25, 1930, pp.365-426.

Gray, A. and Parker, R.J. "The Copper Deposits of Northern Rhodesia". Eng. and Min. Journ. Vol.128, 1929, pp. 384-389.

Lindgren, W. "Mineral Deposits", 1933.

The Katanga deposits are generally similar to those in Northern Rhodesia. The ore is found in a series of short erratic veins, mainly in shattered and folded dolomite. The ore mineral of cobalt is linnaeite, which is often associated with pitchblende. Other minerals found in the veins are pyrite, carollite, pentlandite, chalcopyrite, bornite, chalcocite, covellite, molybdenite, gold, wulfenite, calcite, quartz, and tourmaline.

Thoreau, J. and R. du Trleu de Terdonck. "Le Gite d'Uranium de Shinkolobwe-Kasolo (Katanga)". Hayez, Bruxelles,1933.

Summary in "Mineragraphy of the Ores of Great Bear Lake" by D.F. Kidd and M.H. Haycock, Bull. Geol. Soc. Amer. Vol.46, 1935, pp. 879-959.

The early stage of mineralization was characterized by quartz, monazite, tourmaline, and the formation of some chlorite, talc, and sericite. This was followed by the introduction of the metallic minerals and finally, by large quantities of calcite.

The Moroccan deposits have also proved a major source of cobalt. The veins intersect Precambrian granite, gneiss and schist. The vein width varies up to several meters

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Orcel, J. and Jourausky, H. "Le minerai de Cobalt de Bou Azzer (Maroc). Sa composition minéralogique". Abs. U.S.N.R.C.Ann. Bib. Econ. Geol. Vol.10, 1937.

with a variable content of metallic minerals. The mineralization consists of smaltite, chloanthite, skutterudite, safflorite, rammelsbergite, arsenopyrite and loellingite, and in places good values in gold. The genetic relation to a parent magma is not known.

Cobalt occurrences are known in South Africa. Mendelssohn describes a vein found along a contact of a basic dike with the Main Reef Series. He reports the following order of deposition: apatite, quartz, cobaltite, chlorite, pyrrhotite and gold. The vein is mainly a replacement of the country rock.

Many other minor occurrences of cobalt ore have been noted. Kremchukov, Krutov and Borisevich have described a Caucasian ore bearing zone in limestone which has been invades by Tertiary granite. The minerals consist, in paragenetic order, of arsenopyrite, cobaltite, pyrite, molydenite, chalcopyrite, bornite, sphalerite, and galena. The ore is apparently related to the granite.

Mendelssohn, E. "Notes on a Vein Containing Cobaltite, Gold and Apatite on the Far East Rand". Geol. Soc. S. Africa, Trans. 35, pp. 191-192, 1933.

Krutov, G.A., Kremchukov, G.A., and Borisevich, N.U. "Cobalt Deposits of the Caucauses". Abs. in U.S.N.Rc. Ann. Bib. Vol.IX, 1936.

J.A. Dunn has described the following minerals in the Bawdin ores of Burma: cobaltiferous loellingite associated with pyrite, arsenopyrite, gersdorffite, ankerite, sphalerite, chalcopyrite, cubanite, tetrahedrite, galena, bournonite, boulangerite, pyrargyrite and calcite. The ores lie in a shear zone replacing tuffs preferentially to rhyolite. The rocks are intruded by granite, but the nearest exposed body of this granite lies some miles from the ore body.

Gardiner, in a study of Phillipine deposits found that ores containing loellingite with silver ores sphalerite and galena. The ore lies in a highly silicified zone near a granite intrusive.

Dunn, J.A. "A Microscopical Study of the Bawdin Ores, Burma". Geol. Survey of India, Records 72(3) 1937, pp. 333-359.

Murdock, Joseph and Gardiner, Dion L. "Loellingite from the Phillipine Islands". Econ. Geol. Vol.37, pp. 69-75.

GENESIS OF COBALT-NICKEL-SILVER ORES

Many of the cobalt deposits noted about are not of the typical cobalt-nickel arsenide silver type. Others, such as the deposits at Erzgeberge, Cornwall, Great Bear Lake, and some deposits of the Southern United States are remarkably similar to the Cobalt Ontario ores.

The evidence of a genetic relationship of this type of vein with acidic magmas is striking. A study of the deposits noted above reveal the following evidence favoring such a genetic relationship:

(1) Such veins are nearly always areally related to acidic intrusives; (exceptions: Cobalt Ontario and the South African cobaltite occurrences.)

(2) Zoning of the deposits, such as at Cornwall indicate a relation to the acidic intrusives;

(3) The occurrence with tourmaline indicates a hydrothermal origin related to acidic rocks;

(4) The association with the ore minerals of tin, tungsten, uranium, and with native bismuth indicates an acidic parent magma;

(5) Wall rock alteration, such as in the Cobalt deposits, indicates solutions high in silica and often rich in soda, accompanied the mineralization. Such accompanying solutions are more common with acidic intrusions.

The close association of the Cobalt ores with a rock as basic as the diabase is highly anomalous, and the exact nature of the association has been a subject of much discussion. Since the problems of genesis of the Cobalt ores might be applicable to other deposits of the region, they are of more than passing interest.

The various theories of their origin can be conveniently grouped into three categories:

I- The ore deposits are residual differentiates of the diabase sill;

II- The ores came from the same parent magma as the diabase;

III- The ores are derived from a younger underlying magma which is unrelated to the diabase.

I. Since the ore at Cobalt lies within or near the diabase many earlier examiners assumed the ores to be derived from the magma which formed the sill. The theory has been generally discarded because:

(a) A number of deposits lie along or are closely related to faults which cut the diabase. The displacement on these faults range up to 550 feet, as on the Cobalt fault. It is thus apparent that not only was the sill solidified before mineralization occurred, but that faulting intervened.

(b) The dike itself would surely show at least patches of high mineral content if differentiation progressed from diabase to ore bearing solution. Moore made

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Moore, E.S. "Genetic Relationship of Keweenawan Diabase and Ore in Ontario". Econ. Geol. Vol. XIX, pp. 752-53, 1934.

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several careful analysis of the diabase to determine the silver content. Although silver was found to be present, the amounts were generally too small to be measured. Bastin says the mineral content of the diabase is no higher than in certain batholiths of the Western States which are unrelated to any known ore deposit.

(c) In the Cobalt area the diabase sill is uniform in composition, showing no trace of differentiation.

II. Several authors have supported the hypothesis that the mineralizing solutions responsible for the deposition of the ores are a late phase product of the differentiated magma which produced the diabase.

That intrusives later than the diabase are present is proved by the aforementioned "aplite" or "red rock" dikes. Although the occurrence of such dikes is limited to one in the Cobalt region, they are more common in the outlying districts, especially in the area around Gowganda and Elk Lake.

In an effort to establish a relationship between the Nipissing diabase, the acidic dikes, and the ore deposits, W.H. Collins made a careful study of the various facies over

Collins, W.H. "The Quartz Diabases of the Nipissing District, Ont." Vol.5, 1910, pp. 538-550.

much of the area concerned. He found various gradations ranging from typical diabase to a white aplitic dike composed of soda plagioclase, mica, and quartz with some pyrite and chalcopyrite. These acidic dikes often carry large percentages of calcite and occasionally barite.

Collins believes these dikes may represent an intermediate stage in the progressive differentiation of diabase to the final ore bearing hydrothermal solutions. The calcite has been derived from the intruded rocks. Barite is derived in a similar manner and occurs in areas underlain by Laurentian granite, which is cut by veins containing barite.

N.L. Bowen studied these acidic dikes and believes

Bowen, N.L. "Diabase and Granophyre of the Gowganda Lake District, Ont." Jour. Geol. Vol.18, pp.658-674, 1910.

them to be the result of soda rich solutions acting on a diabase. He believes the soda solutions are an end stage product of the magma which produced the diabase.

Thus Bowen and Collins agree in relating the acid dikes to the diabase, but disagree on their origin. Either solution admits the possibility of differentiation of the diabasic magma to an acidic end stage product, supposedly in part ore bearing.

III. A third hypothesis for the formation of the "acidic dikes" is advanced by E.S. Bastin. He also believes there is a close genetic relationship between these dikes and ore formation. Like Bowan he attributes the acidic rocks to the hydrothermal alteration of pre-existing rocks. Unlike Bowen he finds no evidence relating the solutions to the diabase.

Bastin describes ore minerals in a calcite gangue forming the centre of veins. The veins grade outward into quartz, aplite, and finally to diabase. The alteration next to the acidic dikes is similar to the wall rock alteration of the ore bearing veins in the district. Bastin also finds that all contacts with the acidic dikes are gradational, though some microscopically so. The gradation supposedly indicates varying degrees of hydrothermal alteration and the presence of ore in the centre of the vein proves genetic relationship.

Tanton (in Moore) describes these "red rocks" in the

Bastin, E.S. "Aplites of Hydrothermal Origin Associated with Canadian Cobalt-Silver Ores". Econ. Geol. Vol.30 1935, pp.715-734.

Moore, E.S. "Genetic Relationship of Keweenawan Diabase and Ore in Ontario." Econ. Geol. Vol.XIX, 1934.

Port Arthur district. He finds them grading into quartz diabase to diabase on one side, and through a mottled altered rock to sediments on the other. This supports the hypothesis of Bastin as well as Bowan.

If the dikes are magmatic injections as Collins believed, then the gradational effects noted constitute strong evidence of a genetic relation between ore and diabase. However, if the dikes are the product of hydrothermal alteration, their age is simply determined as post-diabase. In such a case they may be related either to the diabase or to a later intrusive which has not yet been uncovered in the Cobalt region. The fact that no later intrusive has been discovered in the Cobalt district has led to the general adoption of the former hypothesis.

It is interesting to note that Bastin has found, in the area near the old Bruce copper mine, a mineral vein cutting a granite which is post diabase. (Bastin believes the Bruce Mine copper veins showed a number of similarities to the Cobalt veins). This would indicate a pre-mineral post-Nipissing granite intrusion.

It is also possible that the acidic dikes have more than one origin.

Bastin, E.S. "Aplites of Hydrothermal Origin Associated with Canadian Cobalt-Silver Ores." Econ. Geol. 30, pp. 715-734, 1935.

STRUCTURAL CONTROL

Since the diabase dikes and sills in the Cobalt district had solidified and undergone a period of faulting before the period of mineralization, the localization of the deposits in and about the diabase must be entirely due to structural control, regardless of the source of the minerals.

The Bruce and Cobalt series with the Keweenawan dikes and sills form a relatively thin blanket over the Kewatin basal complex. The diabase sill at Cobalt ranges from 800 feet to 1250 feet in thickness, the Bruce and Cobalt series up to 2500 feet. In extreme cases this cover may reach 15-20,000 feet. Such a blanket covers the Kewatin complex throughout an area of about 5000 square miles. It is possible that during a period of minor disturbance, the highly folded schists, greenstone, flows and sediments of the Kewatin series would yield more or less plastically, while the diabase in the overlying blanket would act as a brittle strut and yield by fracturing and faulting, providing solution channels.

E.L. Bruce, in a study of certain silver deposits

Bruce, E.L. "Silver Veins North of L. Superior" in Ore Deposits as related to Structural Features, Edited by W.H. Newhouse.

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in the Thunder Bay District found ore concentrated around diabase and in brittle rocks next to the diabase. He believes the fracturing of these more brittle rocks has exercised structural control over the deposits.

Moore has found the ores north of Lake Huron have a greater tendency to form in and near sills than in or near dikes, which also implies a structural control.

However, the matter of structural control for the Cobalt ores is at present a matter of conjecture, and it is not the intention to present a lengthy discussion on the matter, but merely to express the plausibility of such control.

Moore, E.S. "Genetic Relationship of Keweenawan Diabase and Ore in Ontario". Ec. Geol. XIX, 1934.

ORIGIN OF THE FIELDING DEPOSIT

The deposit on the Fielding property has several features in common with other cobalt deposits in the world. A comparison with the deposits at Cobalt Ontario reveals the following similarities:

(a) Both have a high content of cobalt and nickel arsenides and sulpharsenides.
(b) Both are areally associated with Nipissing diabase.
(c) Both show a general albitisation and sericitization of the wall rock.
(d) Both have a gangue of calcite and quartz.

The lack of silver, the presence of tungsten, and the large proportion of pyrrhotite in the Fielding deposit is in sharp contrast with the Cobalt deposits, but are features which might normally be expected in a deep seated, high temperature equivalent of them.

Since the deposit on the Fielding property is similar to the Cobalt deposits, lies within the same metallogenic province, and presumably was formed in the same metallogenic epoch, the same theories of genesis might be applied. That is the ores may have been derived from the magma which produced the diabase, or it may have been derived from a later intrusive.

The only evidence linking the mineralization to the diabase is indirect, namely that since no post-diabase intrusive mass is found in the Cobalt region the Cobalt ores may be genetically related to the diabase, therefore the Fielding deposit, being similar to the Cobalt deposits, may also be related to the diabase.

Diabase on the Fielding Property which is no more highly altered than some of the other diabase in the district, shows a crushing of the secondary albite, and the fractures are filled with quartz calcite and alkali feldspar; also the calcic feldspar formed with the vein is not albitized. This may indicate that metamorphism preceded faulting, which was followed by the introduction of vein material, thus indicating a large time interval between the diabase intrusion and ore formation.

About 15 miles west of the Espanola sheet lies the Cutler batholith. This is of Killarney age and is later than all the diabase in the district except the olivine diabase. The granite is somewhat more quartzose than typical Killarney granite. It has numerous pegmatites associated with it. In the Lake Panache area, ten miles to the east, Collins has also mapped Killarney granite. This granite is also younger than Nipissing diabase and older than the olivine diabase. Therefore, with Killarney age granite to the west, and Killarney granite to the east, it is highly probable that granite intrusives underlie the Espanola area. The aplite dikes on the Fielding property may be related to this granite.

Therefore, in discussing the genesis of the Fielding deposit, one is not embarrassed by the lack of an acidic source as in other areas of the Cobalt province. The evidence suggesting an acidic source for the cobalt-nickel-arsenide type of deposit has already been cited. The presence of tungsten in the Fielding property is suggestive of a relation to the granite intrusives rather than to the diabase.

Although this deposit is considered to be related to the granite intrusives it is fully realized that no conclusive proof is offered. The origin of the various ore deposits north of Lake Huron has defied satisfactory solution despite years of careful observation and research. The presence of the tungsten simply adds to the evidence suggesting a source other than the diabasic magma.

Of the gangue minerals the quartz was probably derived from the parent magma. However, leaching of the intruded rock may account for a portion of it. The presence of secondary bytownite with myrmekitic quartz indicates a release of quartz by metamorphic reactions. The passage of the mineralizing solutions through the underlying Bruce sediments as well as the Kewatin complex, may have provided a source for a portion of the quartz.

The calcite may have been derived from the Kewatin complex, the Bruce sediments, or from the diabase. Since the hydrothermal alteration of the wall rock would yield calcite, a continual supply might be expected as long as the mineralizing solutions maintained their flow, but as leaching became more thorough the supply would diminish. If, near the beginning of mineralizing period, metamorphism along the vein walls had not proceded far enough to yield calcite, little calcite would be present. This would explain the early stages being characterized by barren quartz with apparently little calcite.

If the calcite is derived from the intruded rocks, it would be independent of differentiation in the magma. The period of maximum deposition could vary with the type of rock intruded, minor variation in the transporting fluid, and the conditions of deposition. Thus, if the calcite deposition could vary from place to place, and continued over much of the period of mineralization, conflicting evidence as to its place in the sequence of deposition could easily arise.

SUMMARY AND CONCLUSIONS

The remnants of an ophitic texture in the greenstone on the Fielding Property prove it to be an alteration product of diabase, which is believed to be of Nipissing age. The labradorite of the original diabase has been saussuritized to an albite-epidote-zoisite-clinozoisite mixture, and the pyroxene has altered to actinolite-tremolite and chlorite. The albite contains an abundance of scaley alteration product, probably sericite. In the vicinity of the vein numerous small stringers of calcite are found cutting the greenstone.

In the "intermediate zone" of pit No.1 calcic plagioclase is found associated with scheelite, quartz and orthoclase of hydrothermal deposition. The fact that this plagioclase is not albitised may indicate that it (together with the scheelite etc. deposition) was formed after the albitisation of the diabase. This would place the albitisation previous to or contemporaneous with the introduction of large masses of barren quartz early in the preiod of mineralization.

The gangue minerals of the deposit are mainly calcite and quartz, but tremolite, sericite, talc, graphite, magnetite, and chlorite are present. The quartz has the same source as the metallic minerals, but the calcite is believed to be derived from the alteration and leaching of underlying rocks by the ascending hydrothermal solutions.

The introduced minerals in order of their periods of maximum deposition are: quartz; calcite; scheelite and ferberite; cobaltite, gersdorffite, loellingite and skutterudite; chalcopyrite; pyrrhotite and polydymite.

The brecciation of calcite and cobaltite and the slight shearing noted in some of the pyrrhotite indicate that mineralization was interrupted by movement in the zone of deposition. Since the massive sulphide contains numerous angular fragments of calcite, and the pyrrhotite shows shearing only in a few grains, the movement presumably took place during the early stages of pyrrhotite deposition. It is also probable that the movement consisted of several minor displacements, though no proof of this was found.

The deposit on the Fielding Property has several features in common with other cobalt deposits of the world, and is believed to be a high temperature equivalent of the Cobalt Ontario type of vein. A telescoping of the Cornwall type of deposit would result in a tungsten-cobalt association very similar to the one described here.

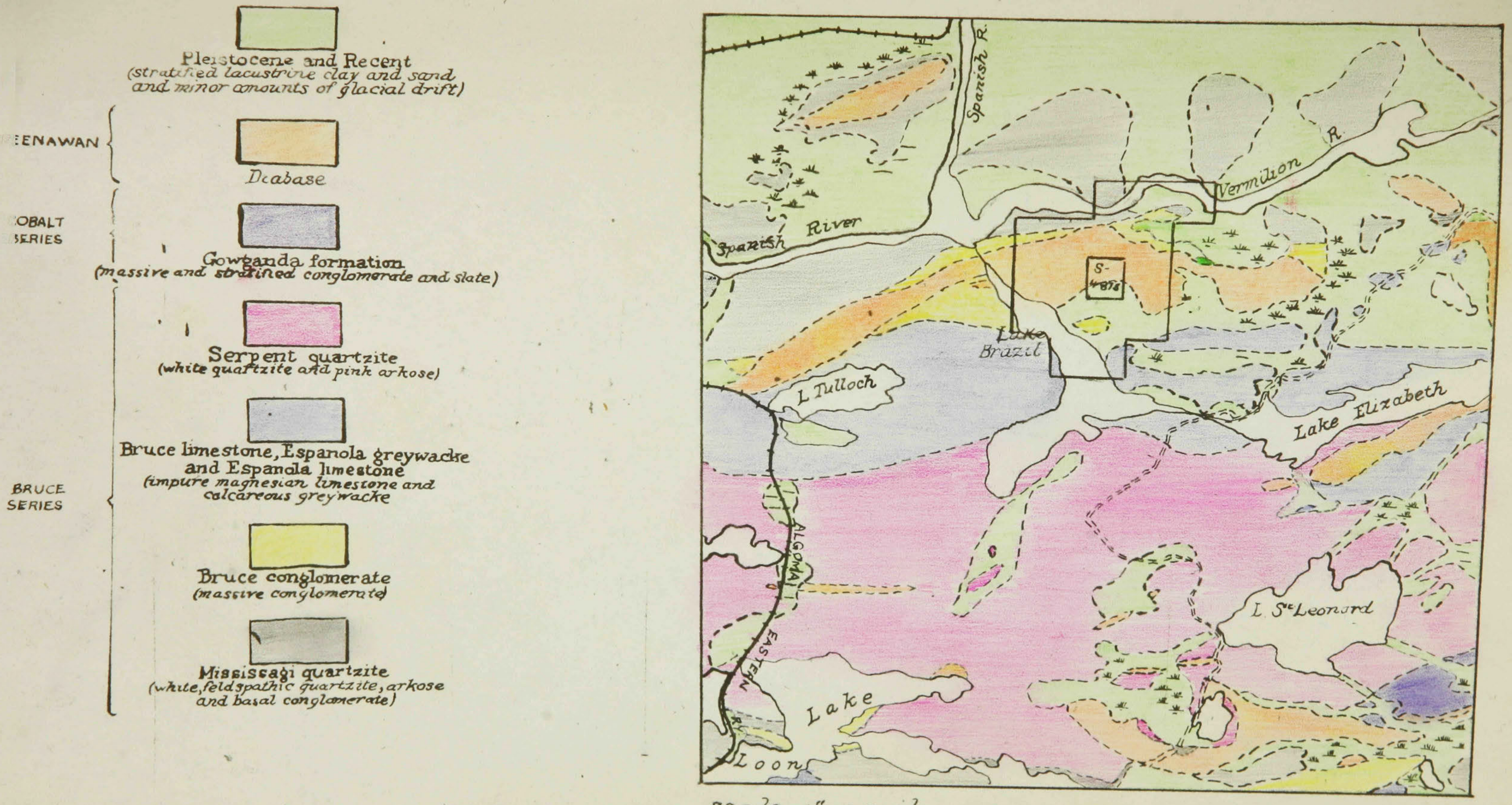
The deposit is probably related to an acidic intrusive, possibly of Killarney age because:

(a) This type of deposit is generally associated with acidic intrusives.

(b) The presence of scheelite and ferberite are indicative of an acidic source.

(c) Aplite dikes, such as are found on the property are more common around acidic intrusives.

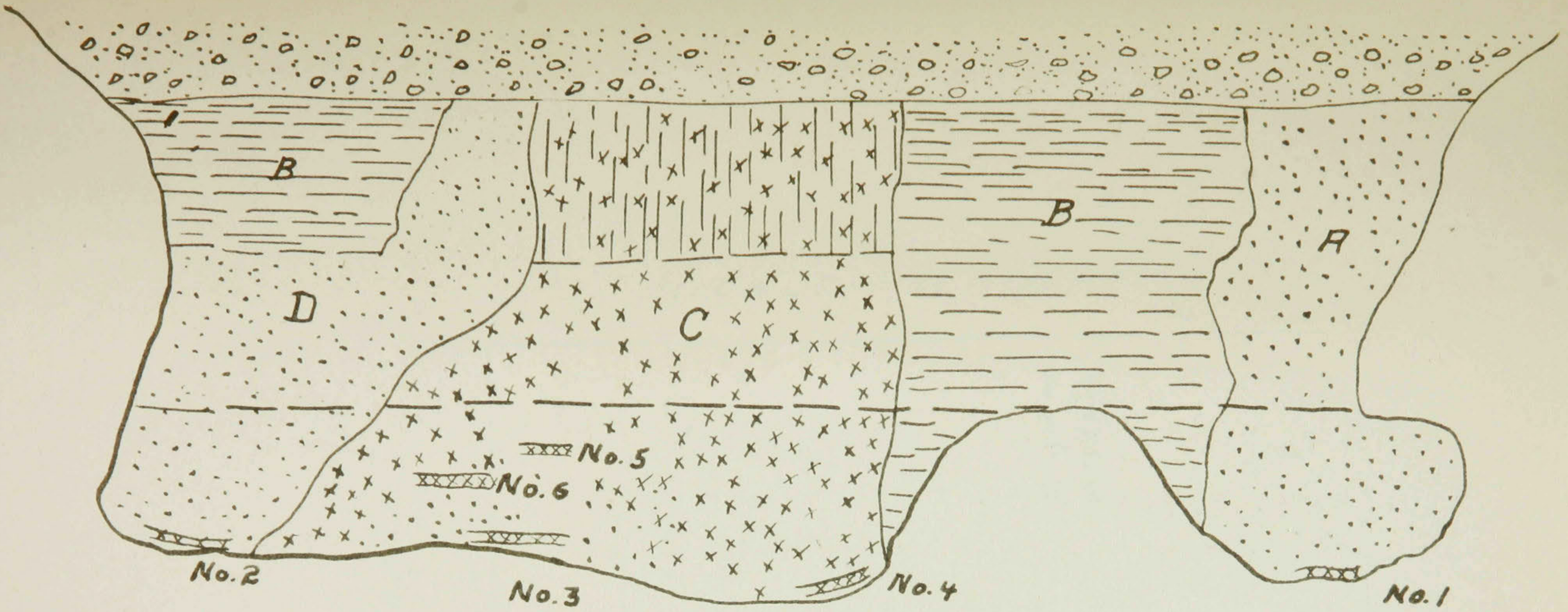
(d) Killarney age granite is found both to the east and west of the area.



scale 1" = 1 mile

geology after T.T. Quirke

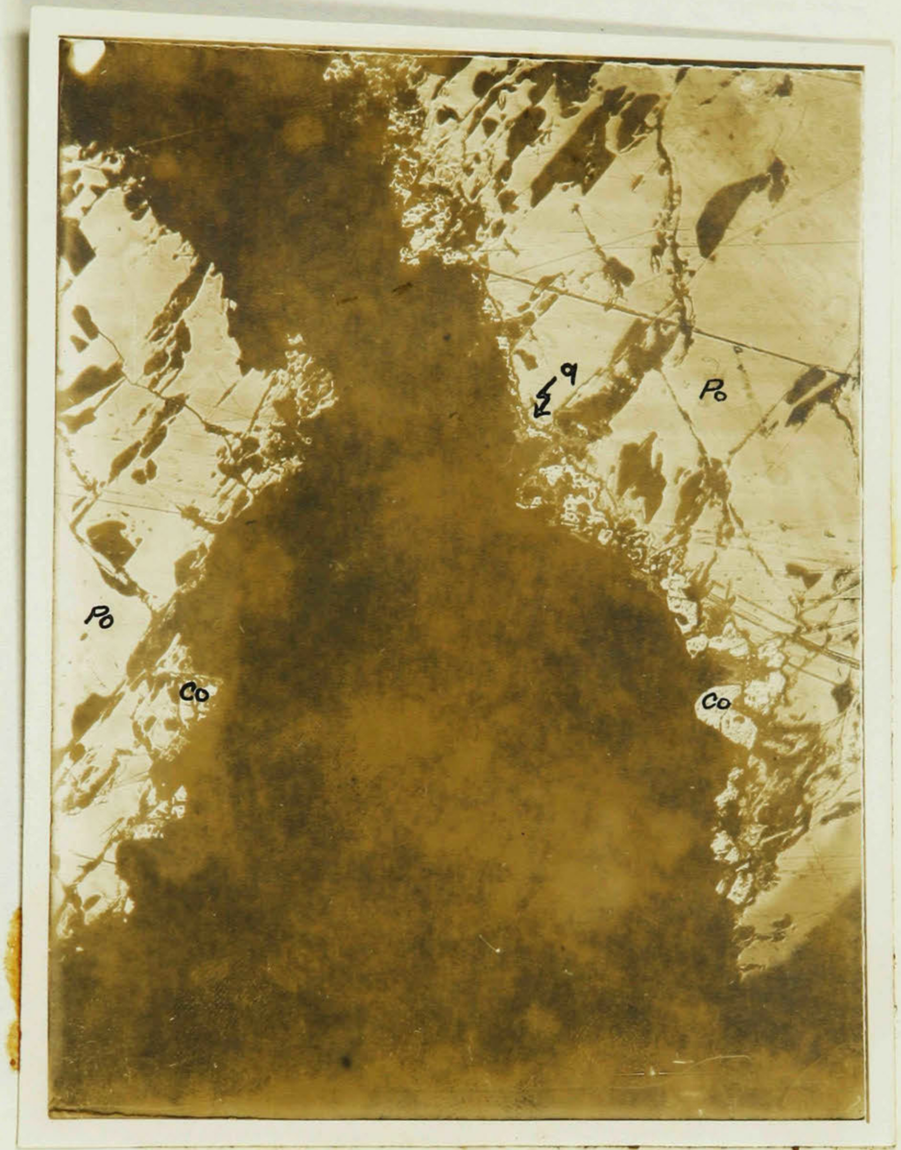
PLATE I



longitudinal section
PIT NO. 1
scale 1" = 5'

▨	*Massive Sulphide Zone*
▨	*Carbonate Zone*
▨	*Intermediate Zone*
▨	*Quartz*
▨	*Overburden*
▨	*Fault*
▨	*Area Sampled*

PLATE V



X 100

Cobaltite (Co) and quartz (q) bordering a carbonate (black) veinlet which cuts pyrrhotite (Po).

PLATE VI

X 50

Tiny veinlets of pyrrhotite (Po) between fragments of broken cobaltite (Co) in a carbonate (black) groundmass.

PLATE VII

X 50

Cobaltite (Co) replacing calcite (black) along cleavage planes. Skutterudite (S).

X 100

Cobaltite (Co) borders on a veinlet of pyrrhotite (Po) which cuts carbonate (black).

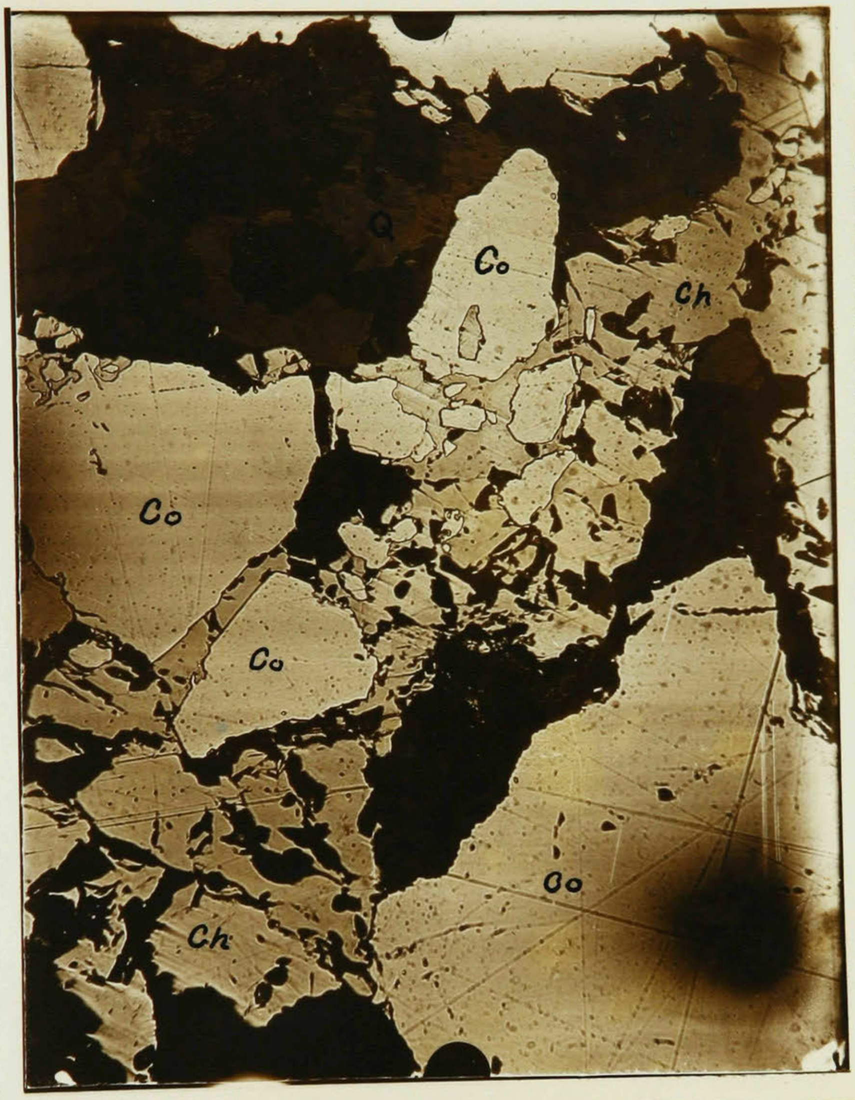
PLATE IX

X 100

Gersdorffite (G) replacing all greenstone minerals (dark grey and black) except laths of tremolite.

X 400

Gersdorffite (G) and loellingite (L) replacing greenstone (black). A portion of the border has been inked in to bring out the angularity which could not be properly photographed under high magnification.



X 50

Shattered cobaltite (Co) enclosed by chalcopyrite (Ch). Quartz (Q), calcite black.

PLATE XII

X 50

Border of chalcopyrite (Ch) between pyrrhotite (Po) and carbonate (black).

X 100

Polydymite needles (etched) in pyrrhotite.

PLATE XIV

X 100

Lath of ferberite (F) imbedded in gersdorffite (G). Greenstone minerals (black).

APPENDIX

D. D. H. No. I

Dip 45° Length 201'

Footage	Description
0 - 4.0	Casing
4.0 - 18.2	Diabase - med. grain - grey greenish
18.2 - 25.0	White quartz - barren
25.0 - 26.0	Massive sulphide - chiefly pyrrhotite - little chalcopyrite
26.0 - 27.0	White quartz - few blebs of chalcopyrite
27.0 - 32.0	White quartz - 15% massive sulphides in 1" to 2" stringers (few stringers of tremolite)
32.0 - 49.0	Massive white quartz - no visible mineral
49.0 - 53.5	Contact zone - diabase - light pinkish alteration - very low patchy finely dissem. sulphides.
53.5 - 93.2	Diabase - dark grey green - fine to med. grain
93.2 - 100.7	Diabase - coarse porphyritic phase - mottled with feldspar 1/8".
100.7 - 127.5	Diabase - fine to med. grain.
127.5 - 146.5	Diabase - light grey med. grained
146.5 - 148.0	" - brecciated
148.0 - 201.0	" - med. to coarse grained

D. D. H. No. 2

Dip 30°

Length 295'

Footage	Description
0 4	Casing
4.0 - 21.0	Diabase - med. grained - grey
21.0 - 31.0	" " " - light grey
31.0 - 43.0	" - coarse grained - mottled - siliceous
43.0 - 44.0	" - fine grained - low shear 60° to core axis.
44.0 - 51.0	Diabase - med. to coarse grained - siliceous
51.0 - 53.0	White qtz. - upper contact gradational - lower 45° to core axis - barren.
53.0 - 115.0	Diabase - med. to coarse grain - mottled siliceous patches - (70-75' little fine pyrrhotite and chalcopyrite in fine seams)
115.0 - 125.0	Diabase - darker greenish - med. grained - more basic phase.
125.0 - 132.5	White qtz. - barren
132.5 - 145.0	Diabase - dark greenish - fine grained
145.0 - 147.2	Aplite - fine grained - dark grey (dyke or inclusion)
147.2 - 159.3	Diabase - fine grained - med.grey
159.3 - 220.0	" - coarse grained - siliceous, Quartz diabase.
220.0 - 222.5	Quartz and breccia - no visible mineral
222.5 - 295.0	Diabase - med. to coarse grained.

D. D. H. No. 3

Dip 60° Length 90'

Footage	Description
0 - 4	Casing
4 -92.5	Diabase

D. D. H. No. 4

Dip 30° Length 100'

Footage	Description
0 - 4	Casing
4.0 - 25.0	Diabase - med. grained - grey
25.0 - 27.0	" - pink mottled phase - med. grain
27.0 - 31.5	" - quartz injected - little tremolite
31.5 - 33.5	White quartz - no visible mineral
33.5 - 35.0	Diabase - qtz. injected as above
35.0 - 100.0	" - normal - med. grain - grey.

D. D. H. No. 5

Dip 80°   Length 71.3'

Footage	Description
0 - 3.5	Casing
3.5 - 17.3	Diabase - med. grain - grey
17.3 - 21.7	White quartz - no visible mineral
21.7 - 71.3	Diabase - as above.

D. D. H. No. 6

Logs unavailable.

D. D. H. No. 7

Dip 30° Length 100'

Footage	Description
0 - 5.0	Casing
5.0 - 12.5	Diabase
12.5 - 47.0	" - basic phase - fine grained altered 47.0 contact at 45° to core axis.
47.0 - 59.2	Quartz - white - occasioned tremolite miner. in blebs and small stringers. No visible mineral. 59.2 contact at 45° to core axis.
59.2 - 93.7	Diabase - altered 64.6 - 68.1 few irregular quartz stringers
93.7 - 100.0	Quartz - white - no visible mineral.

D. D. H. No. 8

Dip 30° Length 125'

Footage	Description
0 - 3.5	Casing
3.5 - 125.0	Diabase - alternately porphyritic and fine grained phases.

D. D. H. No. 9

Dip 45° Length 150'

Footage	Description
0 - 8.0	
8.0 - 84.0	Diabase - med. grained - light coloured
	84 contact 45°
84.0 - 89.0	Quartz - white - no visible mineral
89.0 - 107.5	Diabase - as above
107.5 - 109.0	Quartz - white - no visible mineral
109.0 - 111.5	Diabase - as above
111.5 - 113.5	Quartz - white - no visible mineral
113.5 - 150.0	Diabase - as above.

D. D. H. No. 9

Dip 45° Length 150'

Footage	Description
0 - 8.0	
8.0 - 84.0	Diabase - med. grained - light coloured 84 contact 45°
84.0 - 89.0	Quartz - white - no visible mineral
89.0 - 107.5	Diabase - as above
107.5 - 109.0	Quartz - white - no visible mineral
109.0 - 111.5	Diabase - as above
111.5 - 113.5	Quartz - white - no visible mineral
113.5 - 150.0	Diabase - as above.