Geology 409 Problem

6/4/61.

The Mineralogy of the

EMPIRE DEVELOPMENT PROPERTY

on

Northern Vancouver Island.

(With the main emphasis on the

"botryoidal" form of magnetite)

GLEN E. WITTUR.

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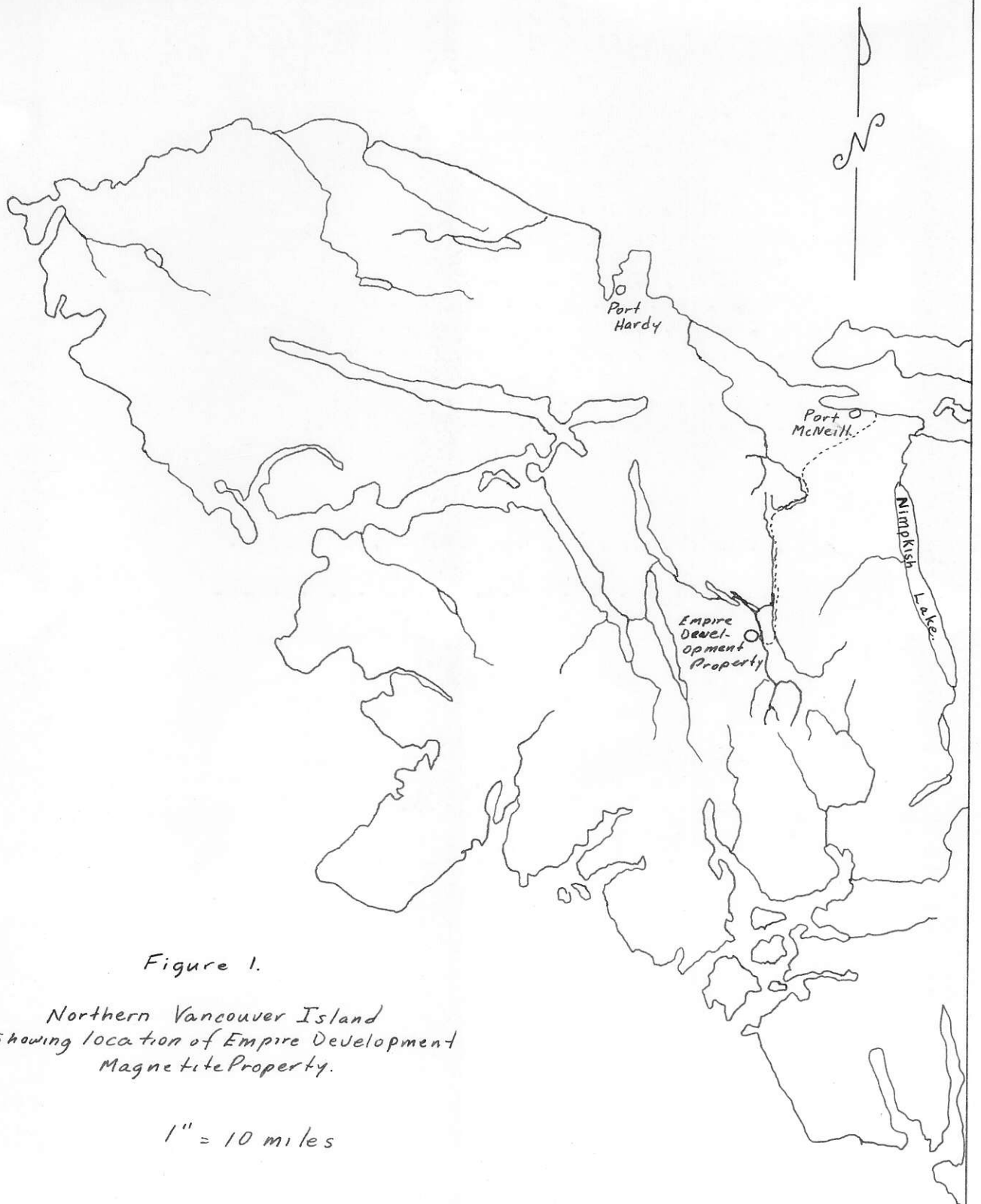
LIST OF ILLUSTRATIONS.

Figure 1.

Northern Vancouver Island
Showing location of Empire Development
Magnetite Property.

1" = 10 miles

ABSTRACT

Although the primary object of this report is a study of the botryoidal form of magnetite which is apparently unique to the Empire Development deposit, it would be incomplete without including a resume of the general geology and mineralogy of the deposit. Therefore the report is divided into two parts; the first gives a brief description of the general geology, mineralogy and paragenesis of the deposit while the second deals with the botryoidal form and other structures of the magnetite.

PART ONE

INTRODUCTION

The mine is located 25 miles by gravel road southwest of the small town of Port McNeill which is on the east coast of Vancouver Island, 17 miles south of Port Hardy Airport. (figure 1.)

The terrain is quite rugged in the vicinity of the mine. The campsite and mill are located on the floor of the Benson Valley at 700 feet above sea level while the mine is situated at about the 2500 foot level of Merry Widow Mountain on the west side of Benson Valley. The highest mountains in the area are about 5000 feet in elevation.

The slopes are steep and covered with heavy timber and dense undergrowth which makes prospecting and mapping very difficult.

The area experiences between 150 and 170 inches of rainfall annually, most of which falls during the winter months. The heavy snowfall at mine elevation forces shutdown of the mine for about three months during the winter but very little snow falls on the valley floor.

The outcrops have been known since the early part of this century. Some exploration work was done during 1930 with copper being the objective but this proved unsuccessful. The availability of a market for iron ore in Japan within the last decade prompted further work on the property in about 1950, this time the objective being iron ore. Sufficient ore in the form of magnetite was proved to warrent going into production so in 1956, Empire Development Company was incorporated to provide the development capital. At the present time Mannix Construction Company is doing the mining under contract.
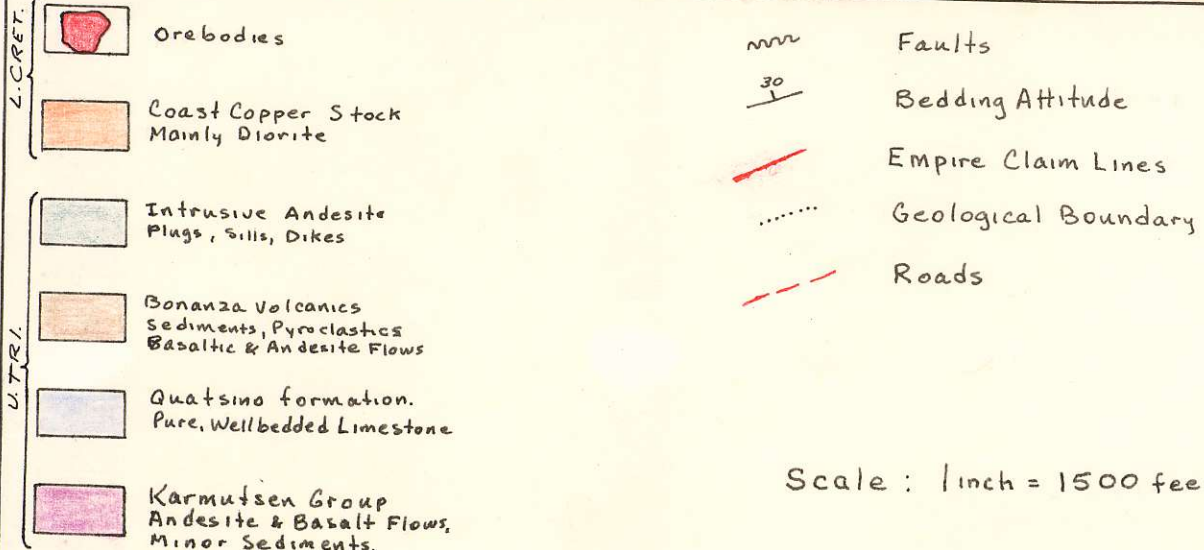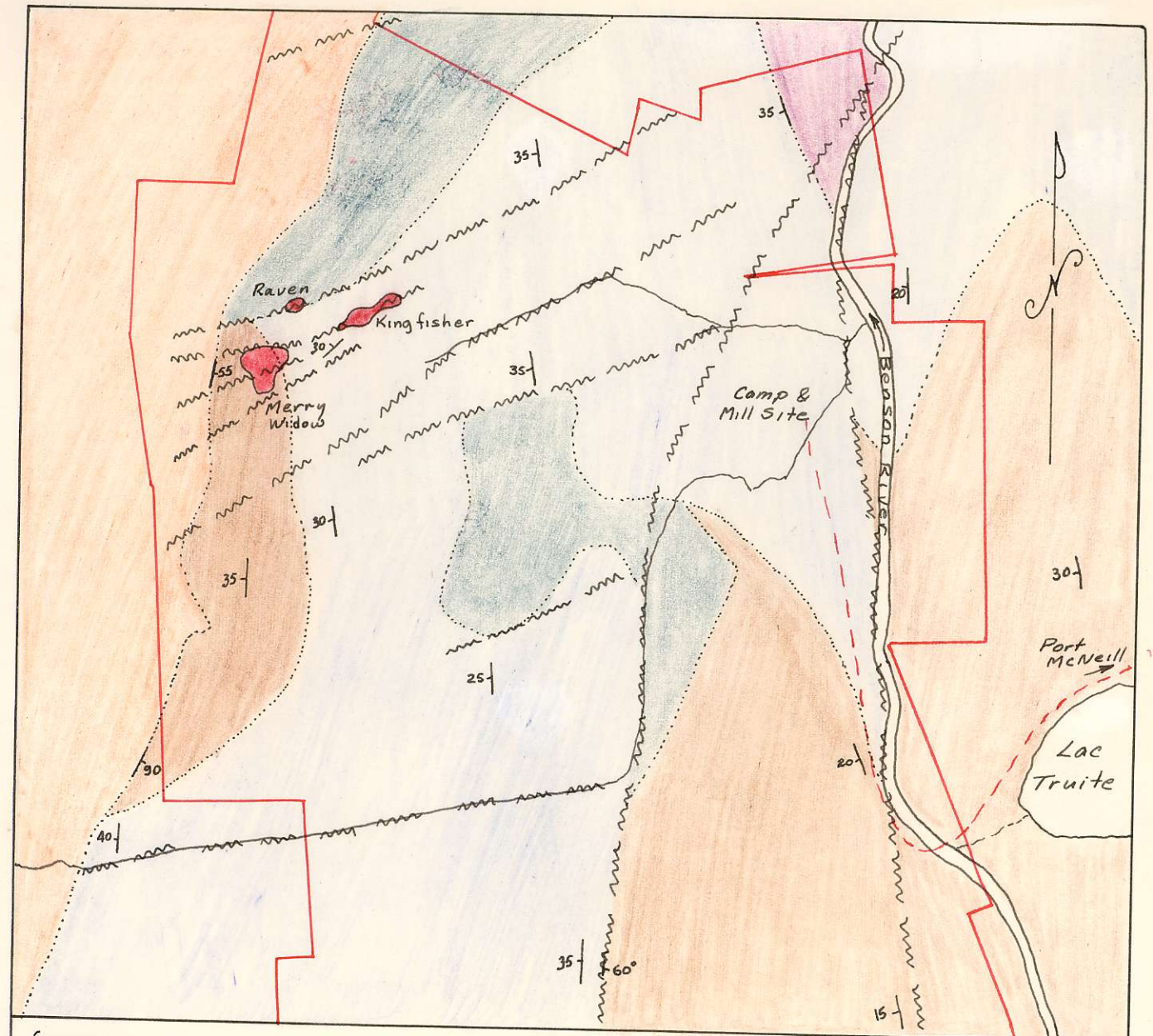
GENERAL GEOLOGY

The area is underlain by rocks of the Vancouver Series of upper Triassic age. This Series is made up of three conformable divisions in the mine area. These rocks strike NW and dip from $10°$ to $40°W$. (figure 2.)

The lower division, the Karmutsen Group, consists predominantly of volcanics, mainly andesite and basalt, with minor lenses of impure limestone and argillite.

Overlying this, with one or two basal interbedded volcanic flows, is the Quatsino limestone formation, composed of 4000 feet of well bedded, relatively pure limestone, more or less recrystallized. Towards its top, it quickly grades into the darker impure limestone, black argillite and pyroclastics, mainly tuff and silicious to limey agglomerate, of the Lower Bonanza Group, the uppermost division of the Vancouver Series. This sedimentary member is usually about 500 feet thick and overlying this is a great sequence of andesite and basalt flows, prodominantly the former, of the Upper Bonanza Group.

The Vancouver Series is cut by several stages of intrusive rocks. The first, in the form of dikes, sills and plug-like

Legend:

- L.CRET.
  - Orebodies
  - Coast Copper Stock Mainly Diorite
- U.TRI.
  - Intrusive Andesite Plugs, Sills, Dikes
  - Bonanza Volcanics Sediments, Pyroclastics Basaltic & Andesite Flows
  - Quatsino formation. Pure, Wellbedded Limestone
  - Karmutsen Group Andesite & Basalt Flows, Minor Sediments.

- ∿∿∿ Faults
- —30— Bedding Attitude
- —— Empire Claim Lines
- ········· Geological Boundary
- – – – Roads

Scale: 1 inch = 1500 feet.

Figure 2.

GEOLOGY OF EMPIRE CLAIMS

bodies up to 2000 feet long, are andesite. These are believed to represent feeders for the upper Bonanza Group and would therefore be part of this group.

The next stage of intrusion was the emplacement of small stocks which range from granite to gabbro in composition, predominantly quartz-diorite and diorite. These stocks are usually elongate, in the order of from 1 to 10 miles long and 1 to 4 miles wide. They are believed to have been emplaced during the Lower Cretaceous Coast Range Batholith Orogeny. The stock in the vicinity of the mine, the Coast Copper Stock, is mainly diorite with some quartz-diorite and gabbro. Associated with this stock are a few aplite and microdiorite dikes, resembling the stock in composition but finer grained.

A third stage, very sparingly represented on Empire property are late basic dikes of relatively fine-grained, dark augite lamprophyre.

Large scale nearly vertical North-south regional faults with dip-slip movement in the order of several thousands of feet follow the Benson Valley. Little is known about these faults but Bonanza rocks on the east side of these faults have been dropped down into the bottom of Benson Valley, to the same elevation as the base of the Quatsino Limestone.

An economically more important fault set is a group of about a dozen faults in the vicinity of the mine which strike generally East-northeast and dip from 70 to 90 degrees to the south. These have evidently been very important as channelways for mineralizing solutions. Every orebody and mineralized zone is associated with at least

one of these faults.

ORE DEPOSITS

The ore deposits occur near the contact between the Quatsino limestone and the Bonanza Group in close proximity to the eastern side of the Coast Copper Stock. The stock dips easterly under the deposits at 55 degrees, although this is only a local occurrance since the stock normally dips almost vertically. The ore occurs both in volcanics which have previously been replaced by skarn and in limestone. There are three orebodies as well as many small mineralized zones on the property.

Merry Widow Orebody.

This is the largest orebody. It occurs in finely-bedded tuff which has been largely been replaced by skarn, with minor projections of ore into the adjacent limestone. The orebody is cut by three east-northeast faults which dip steeply south.

The orebodies consist of several large triangular plates or slabs of magnetite seperated by equal thicknesses of skarn and volcanics. The plates are up to 60 feet thick, 300 feet wide and taper to the east. They dip east, approximately parallel to the underlying diorite of the stock. (figure 3)

The magnetite is generally fine-grained, hard and dense, and contains fair quantities of disseminated gangue. The sulphide content of this ore is low but fair quantities of chalcopyrite and pyrrhotite are seen in the pit.

A couple of small specimens of fine-grained botryoidal magnetite were found in this pit in the late summer of 1960.
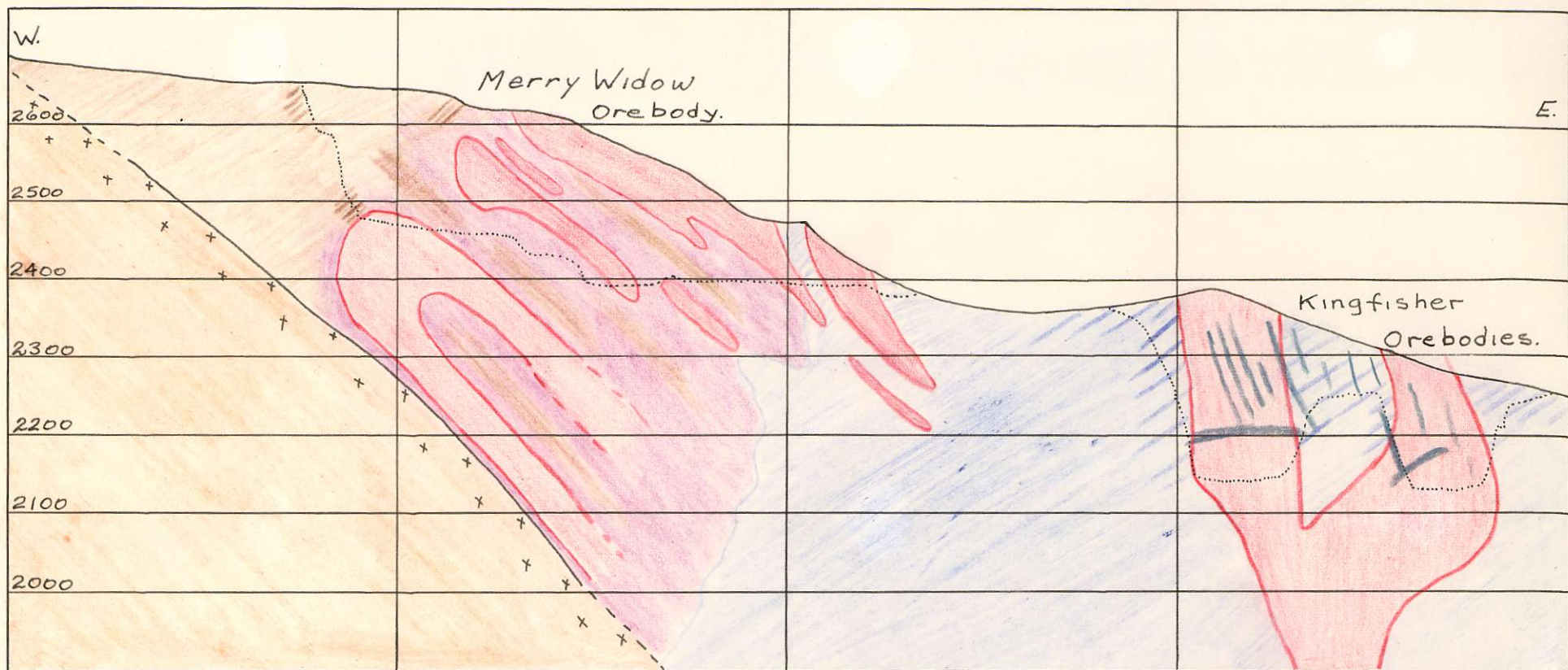
Kingfisher Orebody.

The magnetite in this orebody occurs as two pipe-like bodies which plunge steeply along a east-northeast fault. The pipes are about 90 feet in diameter and have been mined to a depth of over 200 feet. Diamond drilling shows that these bodies continue a further 90 feet where they join and continue downward an unknown distance. (figure 3)

The ore is developed entirely within pure limestone with very little skarn present. Minor amounts of garnet and diopside occur along the margins of andesite dikes which remain unreplaced by magnetite in the orebodies.

Most of the botryoidal magnetite was found in this pit. The ore contains exceedingly small quantities of sulphide minerals. The magnetite is generally coarsely crystalline and friable and commonly shows selective replacement of bedding.

Raven Orebody.

This is a small massive deposit of magnetite occurring in skarn-replaced volcanics along a east-northeast fault. The deposit contains significant amounts of sphalerite and pyrrhotite and minor chalcopyrite which must be carefully picked out while mining the deposit.

Cross Section of Merry Widow & Kingfisher Orebodies.
(looking Northwest)
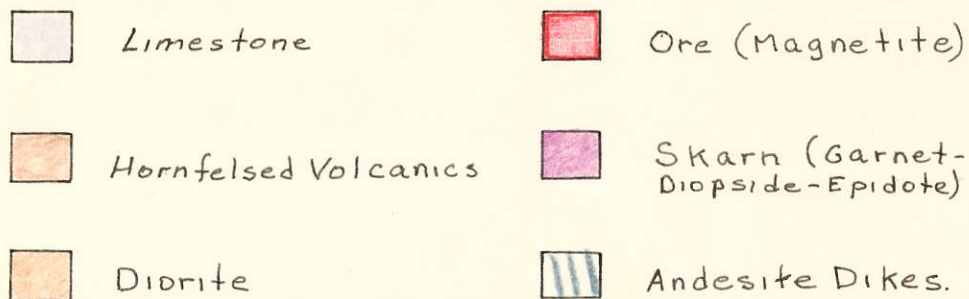
▢ Limestone		▢ Ore (Magnetite)		⋯⋯ Pit outline on July 16, 1960.
▢ Hornfelsed Volcanics		▢ Skarn (Garnet-Diopside-Epidote)		Heavier colored, subparallel lines schematically represent bedding in volcanics & limestone.
▢ Diorite		▨ Andesite Dikes.		Scale: 1 inch = 200 feet.

Figure 3.

MINERALOGY

The mineralogy of the Empire Development Company is typ-
ical of such contact metasomatic deposits. The mineralogy
of the deposit was studied on a megascopic scale in the
field and in hand specimens and on a microscopic scale in
polished sections. The primary minerals are of three basic
types; lime silicate minerals, oxides and sulphides. In add-
ition, there are several secondary minerals.

Primary metallic minerals

Magnetite- This is the principle and only economic mineral.
It occurs as large and small irregular masses, finely detail-
ed bedding replacement bodies in limestone and disseminated
grains in limestone, volcanics, intrusive andesite, diorite
and skarn. The massive bodies may be very fine grained and
dense or more coarsely crystalline and friable. Magnetite
sometimes replaces limestone in exceedingly fine detail with
alternate beds only one millimeter thick being replaced,
leaving the intermediate beds unreplaced but recrystallized
to calcite. The replaced beds may be traced along strike
into unreplaced limestone. An apparently primary structure
in magnetite sometimes seen in the Kingfisher, rarely in
the Merry Widow, is the "botryoidal" form of magnetite.
This occurs as rounded mammillary hemispheres with a concen-
tric and sometimes a radial structure, up to two or three
inches in diameter, but generally

Pyrite- This mineral is not common. It occurs as thin films
along fractures and as fracture fillings in the Merry Widow,
and as rare crystals in the Kingfisher.

Arsenopyrite- This mineral occurs as masses of coarse crys-

tals near the top of the deep ore plates in the Merry Widow Pit. Small microscopic grains were identified in polished sections from the Raven Pit.

Pyrrhotite-This is one of the most common sulphide minerals in the deposit. It occurs as massive bodies in both the Merry Widow and Raven Pits but has not been identified in the Kingfisher.

Cobaltite-This mineral occurs as microscopic grains in the magnetite, skarn and calcite of the Merry Widow.

Chalcopyrite- Chalcopyrite occurs in about equal amounts to pyrrhotite in the Merry Widow. It also occurs as small masses and as crystals in the Kingfisher and as disseminated exsolution grains in sphalerite in the Raven.

Sphalerite- Sphalerite is not known in the Merry Widow but occurs as large masses in the Raven and as small exsolution grains in chalcopyrite in the Kingfisher.

Secondary minerals.

Marcasite- Marcasite occurs as a supergene mineral ~~follow-ing~~ resulting from the breakdown of pyrrhotite, (as branching reniform growths following fractures in the pyrrhotite.)

Erythrite- Erythrite occurs as bright pink earthy coatings along fractures in magnetite and skarn and as groups of minute crystals with calcite and crystalline epidote, having altered from cobaltite.

Copper Carbonates- Malachite and azurite are rarely seen but they do occur where outcrops are protected from harsh weathering, having been altered from chalcopyrite.

Gangue minerals.

Garnet- Andradite garnet is the most common skarn mineral.
It occurs as large masses of hard, very fine grained material
and occasionally as crystalline fracture fillings.

Diopside- This pale green pyroxene is a common skarn mineral
when it is fine grained and dense. It occasionally occurs
with calcite and chlorite in limestone.

Epidote- Epidote is widely distributed as masses of fine grain-
ed rock with other skarn minerals and as an alteration product
in diorite and andesite.

Calcite- This mineral is common as a gangue mineral in the
Kingfisher and Merry Widow orebodies, where it is coarsely
crystalline and pure white.

Chlorite- This mineral is common in the ore but never occurs
as large masses. It is usually fine grained but occasionally
occurs as micaceous crystals typically filling fractures.

Actinolite- This mineral occurs in very small amounts as green-
black radiating crystals filling cavities in skarn and magnet-
ite in the Merry Widow Pit.

Quartz- Free quartz is rare everywhere on the property but
minor amounts occur as crystalline quartz filling cavities
in the Merry Widow Pit. It is a late stage mineral.

Feldspar- Small amounts of pink or orange orthoclase occur
as finely grained crystalline masses in skarn minerals.

PARAGENETIC SEQUENCE OF GANGUE AND METALLIC MINERALS.

The deposits were probably formed when late stage differentiate hydrothermal solutions permiated the country rock via faults and fractures, depositing their contained minerals in chemically and structurely favourable envioriments, towards the final stages in the crystallization of the diorite stock.

Swanson[1] suggests that all minerals, including skarn, magnetite and sulphide minerals were deposited more or less contemperaneously, as a single "surge" of solutions from the crystallizing magma, containing all minerals, invaded the country rocks.

Uglow[2] argues against this hypothesis. It is his contention that the three types of minerals above were deposited in seperate sequential stages as the temperature and composition of the mineralizing solutions changed while the magma cooled. On the basis of my own evidence from both field and laboratory observations, I would agree with Uglow.

The first stage of mineralization was the large scale replacement of finely bedded tuff by lime silicate or skarn minerals, such as andradite, diopside and epidote.. This, I believe, was predominantly a metamorphic change with little addition of material from the stock. The enviornment is sufficiently limey to provide the necessary calcium for these minerals. There was very little skarn developed in the limestone since it contains little silica or other impurities required for the formation of skarn. The only skarn in the limestone occurs along the margins of andesite dikes cutting the limestone.

1) SWANSON Texada Iron Deposits   GSC Summary Report,1923.
2) UGLOW,W.L. Genesis of the Magnetite on Van.Is. 1926.

The next stage , probably beginning towards the latter part of the first stage, was the deposition of magnetite which replaced both skarn and limestone. Magnetite occurs as veinlets cutting skarn and limestone and there is ample evidence that it has replaced the two as well. The magnetite, near its contact with skarn or limestone usually contains grains of the unreplaced rock, and in the case of limestone, replacement has at times been very selective. Very commonly in the Kingfisher Pit magnetite has replaced some beds a farther distance than others from the center of the orebody.

High temperature sulphides such as pyrite, arsenopyrite, cobaltite and pyrrhotite were probably deposited during or just following this stage. It was not possible to establish the exact order of deposition of these minerals since they do not occur together. However, they are commonly deposited in the order given and they normally crystallize at temperatures above 600 degrees C.[1]

As the temperature of the mineralizing solutions declined, the sulphides chalcopyrite and sphalerite were deposited, probably more-or-less similtaneously. In the Kingfisher Pit, sphalerite occurs as minute star-shaped exsolution grains alonga (111) crystallographic planes in chalcopyrite, indicating a temperature of about 550 degrees C.[1] In the Raven Pit, chalcopyrite has exsolved from sphalerite and occurs as myriads of tiny blade-shaped blebs along (111) and (100) planes in sphalerite, indicating a temperature of about 350 or 400 degrees C.[1]

Calcite started to form at about this time, probably from $CaCO_3$ picked up by the mineralizing solutions on replacement of

1) Edwards,A.B., Textures of the ore Minerals Aust.I.M.M. 1954.

Figure 4.

Paragenetic sequence as summarized on a Vandeveer Diagram.
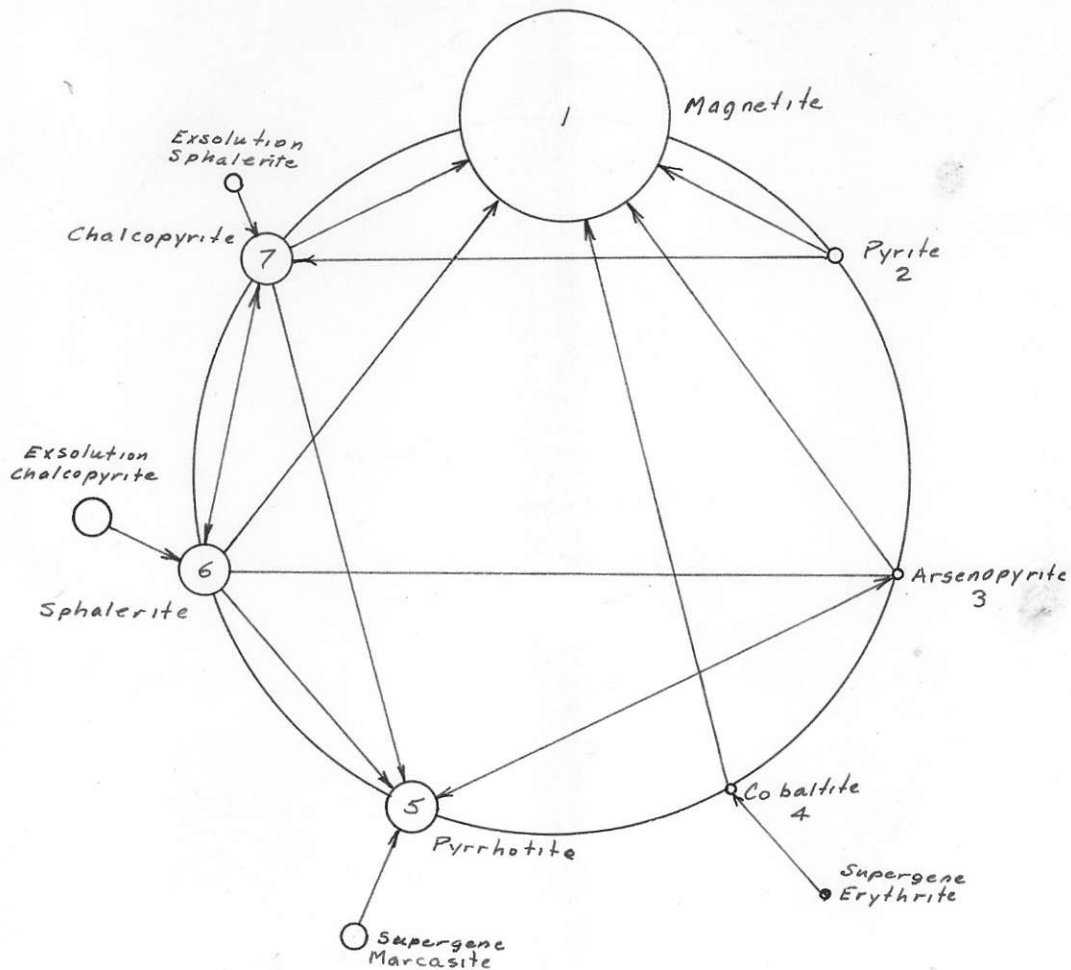
The primary minerals are represented by circles, whose areas represent the relative abundance, around the inner circle. The numbers represent the approximate order of deposition. Minerals seen to be in contact are joined by straight lines and if one has replaced the other, an arrowhead points to the host mineral. Secondary minerals are arranged around the outer circle, as are the exsolution minerals. The circle representing magnetite is much smaller than to scale.

limestone by other minerals.

As the temperature of the solutions declined and became more acidic (?), pyrrhotite became unstable and partly broke down along fractures to marcasite and fine grains of magnetite. This normally occurs at temperatures below 250 degrees C.

Formation of secondary minerals such as erythrite, azurite and malachite occurs under ordinary surface conditions.
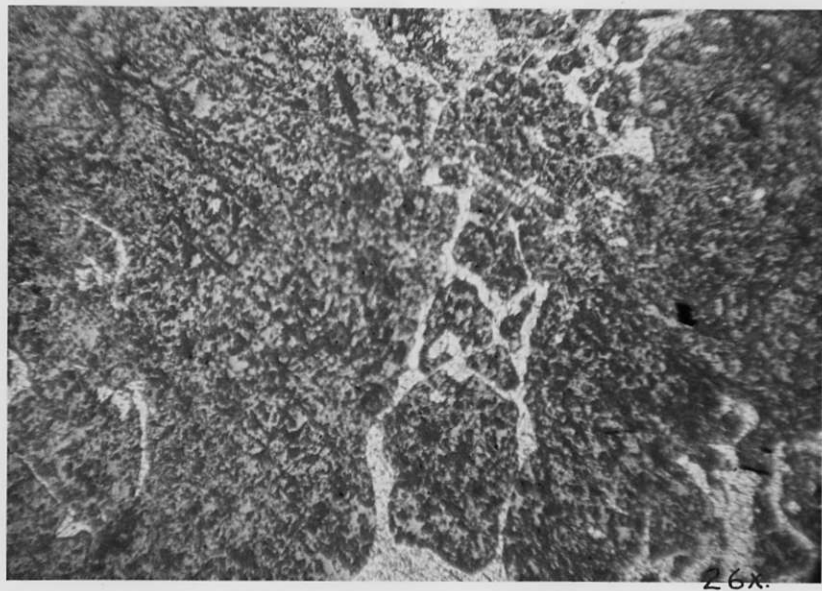
Plate One.
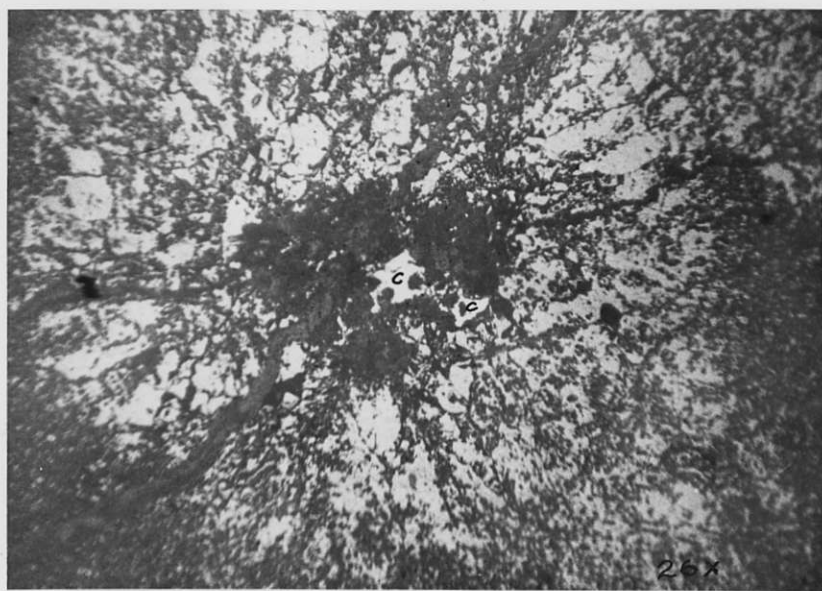Pyrite (light) filling fractures in magnetite.

Plate Two.
Chalcopyrite (C) at the center of botryoidal sphere
of magnetite having been introduced along the fracture
running "north-east" across the photo.

Plate Three.
Magnetite which has replaced fine bedding in limestone.
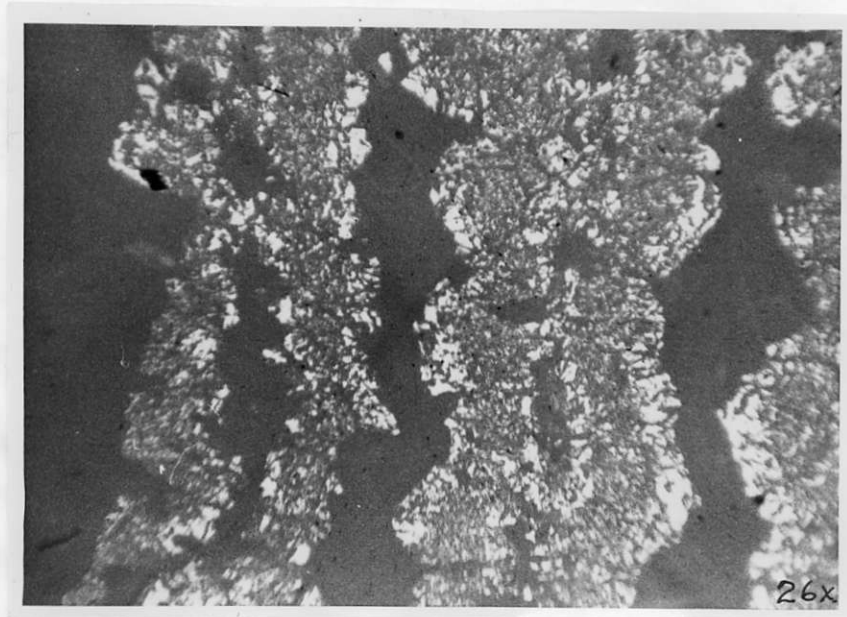Note the faithful reproduction of small folds.

Plate Four.
Magnified polished section of specimen in plate three,
showing how each "bed" is made up of two sheets of
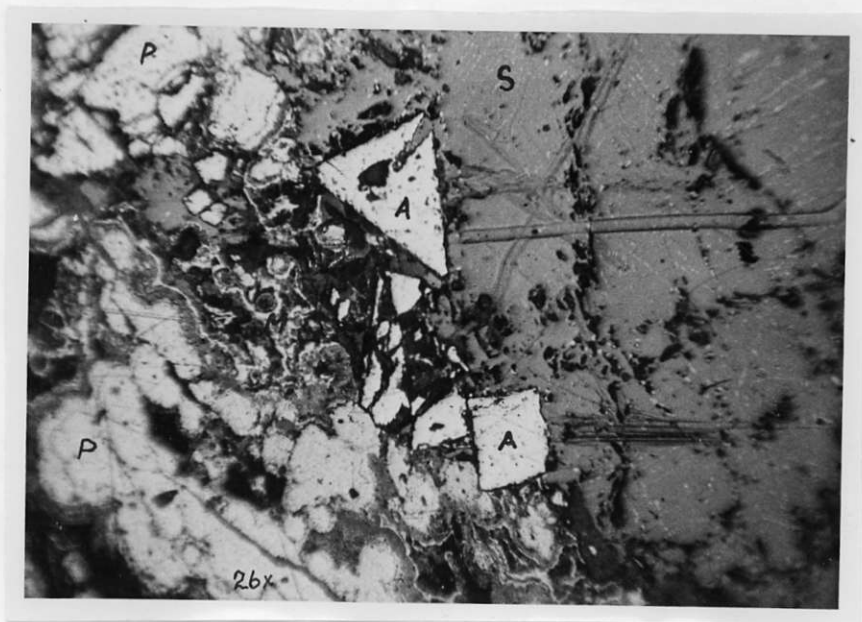magnetite crystals. This specimen was diamond polished.

Plate Five.
Arsenopyrite (A) crystals in sphalerite (S) and pyrrho-
tite (P) which has partly altered to Marcasite (M).
Exsolution chalcopyrite can be seen as minute blebs in
the sphalerite.
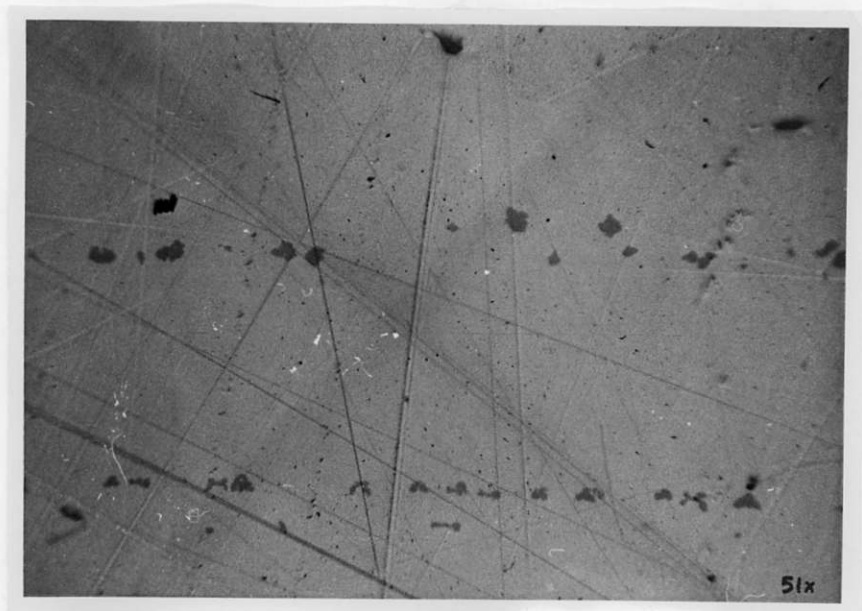
Plate Six.
Exsolution sphalerite (dark gray) along (111) or twin
planes in chalcopyrite from the Kingfisher Pit.

Plate Seven.
Chalcopyrite (light gray) replacing magnetite (darker gray) and chlorite (black) leaving residual grains of magnetite in the chalcopyrite.
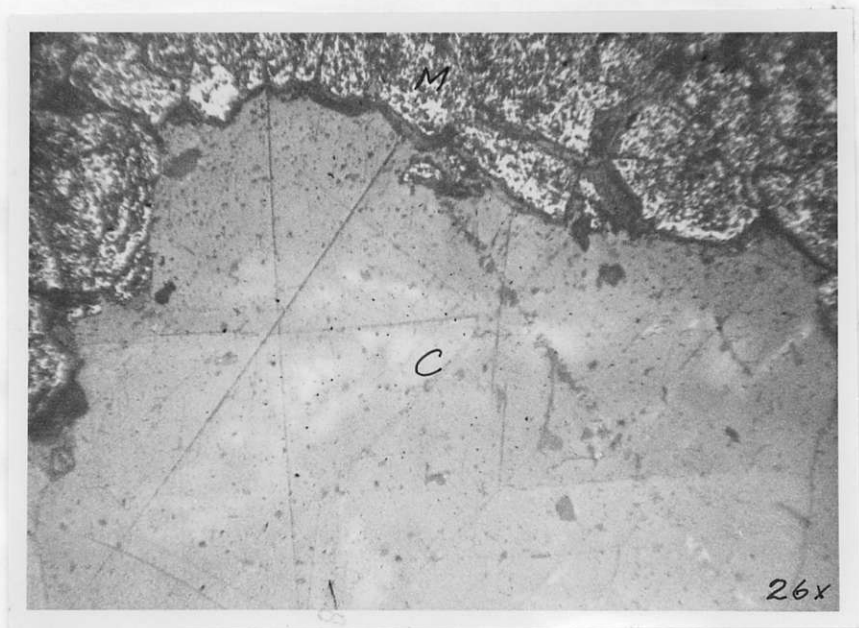

Plate Eight.
Calcite (C) replacing magnetite (M) in a specimen from the Kingfisher Pit.

PART TWO

BOTRYOIDAL MAGNETITE

An attempt to explain the

origin of this form of

magnetite.

PART TWO

INTRODUCTION.

The botryoidal magnetite occurs mainly in the Kingfisher Pit where it is surrounded by (other) massive magnetite or by coarsely crystalline calcite. Two small fine-grained specimens were found in the Merry Widow Pit in the fall of 1960. These occurred near the top of the deeper ore plates.

There are quite a few specimens of botryoidal magnetite available for study. Several polished sections were made.

The mammillary structure strongly suggests that surface tension phenomena have played an important part in the formation of this structure. The process which comes to mind, therefore, is precipitation from a colloidal solution, since a colloid is a suspension of material in such a dispersed state that surface tension plays an important part[1]. The specimens were studied with this in mind and accepted criteria for colloidal formation were searched for.

CRITERIA FOR COLLOIDAL ORIGIN OF BOTRYOIDAL MAGNETITE.

A study of the literature revealed several features which are common to most minerals known to be of colloidal origin, and many of these features were noted on the specimens studied.

The first and most obvious structure is the botryoidal or mammillary habit which has already been mentioned. Several modifications of this basic habit occur. (Plate IX) Either a concentric or a radial structure or both may be present. The concentric structure is due to alternating shells of varying grain size

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1) Latimer and Hildebrand (1956)

which are rarely seperated by thin bands of chlorite or calcite. The radial structure may be due either to radial fractures or to radial allignment of elongated crystals.

When a colloidal solution dehydrates, its volume naturally decreases and various kinds of fracturing typically result. This shrinkage is known as synresis. Four different fracture types were noted on polished sections. The first, already mentioned, is a radial fracturing which is the most common type. A second is concentric fracturing which is parallel to the concentric banding. Bifurcating or septarian cracks, typical of colloidssynresis occur but are not really too common. A fourth type, occurring as irregular net-like fractures, is common. These synresis cracks are usually filled with calcite which was probably deposited from later solutions. (Plate XV)

The interferance surface,formed when two spheres growing towards each other from individual centers, meet,is straight in contrast to the curved outer surface of the sphere. Synresis cracks often follow these surfaces. This structure is especially typical of colloidally deposited minerals.

Grain size varies widely from specimento specimen. Some are very fine grained, typical of colloidally deposited minerals, while others are coarsely crystalline indicating that the magnetite has been recrystallized. One may question the possibility of this sort of recrystallization but Boydell[1] states that "the possibility and even probability of inorganic gel material passing from the micro- to the coarsely crystalline state

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1) H.C.Boydell (1924-25)

is well established".

Where the specimen is fine grained, the structure is predominantly concentric and where the specimen is coarse grained the radiating structure is predominant although concentric str structure is also quite evident. In some specimens, bands of fine grained magnetite alternate with bands of coarse grained magnetite, in which case the coarse bands show a strong radial structure while the fine grained bands usually show none. In this case, the radial structure is a result of allignment of elongated crystals.

In several cases, the specimen shows two distinct "stages" of growth. (Plate X) The two stages are usually seperated by a layer of crystalline calcite coated on either side by a skin of chlorite. (Plate XIII) The surface of the inner stage is usually fairly smooth and has a high lustre in contrast to the outer sphere surface which is usually irregular, if not coarsely crystalline and dull.

The apparent break in deposition of magnetite might be explained by the presence of impurities in the colloidal iron solutions which recrystallized out at particular stages. In a colloidal solution, there are very definate limits to the amount of any one mineral that may be held in suspension. As the colloidal solution dehydrates, this "saturation point" may be reached. If any surplus mineral is present, this will not just settle out as in a true solution, but will instead trigger flocculation and the mineral settles more or less en mass. This would explain why the calcite and chlorite occur as isolated bands and not as disseminations in the magnetite. This composition banding is s common feature of colloidal

formation where more than one mineral forms the dispersed medium.

Very commonly the outer shell of the botryoidal specimen is composed of coarse crystals which are alligned perpendicularly to the banding (Plate XIV) The crystals are commonly terminated with euhedral crystal faces (octahedra). (Plate XI) As the colloid solution filling the cavity dehydrates, it shrinks and this would leave an open concavo-convex cavity. Hydrothermal iron-bearing solutions may pass through the cavity precipitating magnetite which forms the coarse crystals. Ordinarily, for reasons not clear, the crystals appear to grow only pointing away from the convex surface. However, there is one specimen which shows one band of crystals pointing outwards from the convex surface and another outer concentric band of crystals pointing inwards from the concave surface. A thin irregular band of calcite seperates the two bands. In this instance, crystals appear to have grown on both the concave and convex surfaces of the cavity.

The banding or concentric structure does not occur in the center of the botryoidal mass. (Plate XV) The center 1/4 or 1/3 of the total diameter is usually slightly coarser grained than the outer bands and exhibits a rudimentary radiating structure.

Some of the specimens have slight magnetism and when iron filings are sprinkled on a polished surface cutting across the banding, they adhere to some bands and not to others. The magnetic bands in each case are very fine-grained, dense magnetite.

CONCLUSIONS.

There is considerable evidence that the botryoidal magnetite is a product of colloidal deposition. Many structures accepted as criteria of colloidal deposition in minerals definately known to be of colloidal origin were observed in specimens of the botryoidal magnetite. On the other hand, no structures were seen which could not be related to colloid formation or to logical subsequent processes.

If this magnetite is indeed colloidally deposited, the following series of events which may have occurred are proposed by the writer.

Small cavities formed where solution of limestone locally exceeded deposition of magnetite. Molecular magnetite was transported by diffusion into the cavities and crystallized into colloid-sized particles, resulting in a colloidal dispersion. As the concentration of magnetite in the colloid increased, the "saturation point" of the colloid would eventually be reached and flocculation would result, forming a concentric band of fine-grained magnetite about a nucleus. Reconcentration of the colloid solution would then follow by continued diffusion into the cavity. This cyclical process would be repeated many times until the cavity became filled.

The flocculated magnetite may not have been a solid mass upon deposition, but rather a semi-consolidated jel still containing a small amount of the dispersing solution. This solution may have slowly diffused out during which time the magnetite recrystallized and synresis cracks developed.

It is difficult to say what the mineralizing and dispersing

solutions were. Uglow[1] states that they were probably dilute aqueous iron chloride solutions but Holser[2] and Schneer on the basis of experimental evidence, state that this is unlikely and that the solutions are more likely dilute HCl solutions of Fe_3O_4.

The mineralogy of the deposit suggests that it is a high temperature hydrothermal deposit. It is very rare to find any banding or crustification in a hypothermal deposit (high temperature and high pressure) so if open spaces did exist, the deposit must have been formed at a lower pressure. This implies that the deposit was formed at a relatively shallow depth where open spaces were easily maintained. ($< 10,000'$)

1) Uglow, W.L., Genesis of the Magnetite Deposits..... (1926)
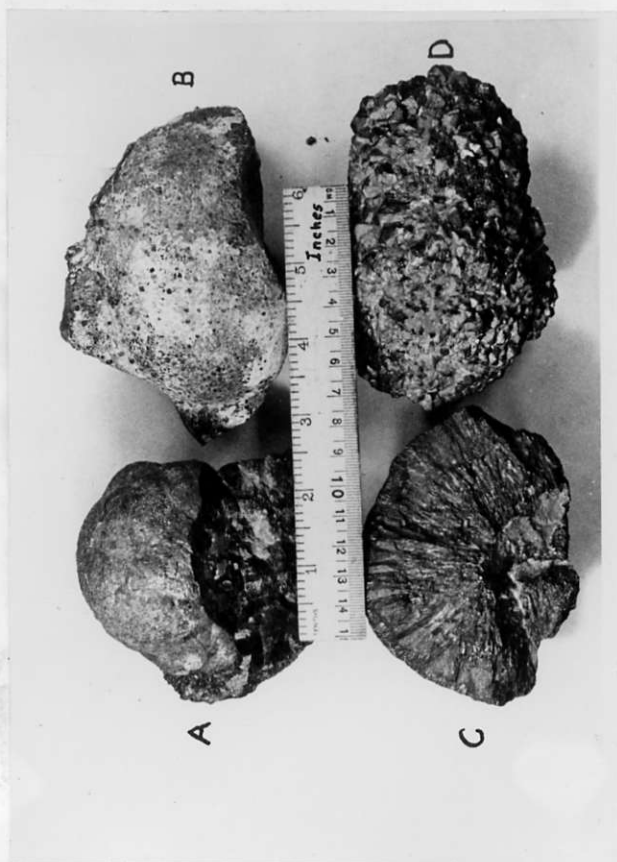2) Holser, W.T. and Schneer   (1961)

Plate IX   Plate X

Plate IX   Four specimens of botryoidal magnetite.
           A) Fine-grained with a smooth exterior surface.
           B) Fine-grained with a rough exterior surface.
           C) Coarse-grained showing a strong radial structure
              and a less evident concentric structure.
           D) Coarse-grained with an outer surface of coarse,
              euhedral crystals.

Plate X   Botryoidal magnetite showing two "stages" of growth.
           The two are seperated by a layer of calcite and
           chlorite not apparent in the photograph.

Plate XI   Plate XII

Plate XI   "Raspberry" magnetite showing a framboidal structure.

Plate XII   Reniform structure in magnetite with an outer layer
              of euhedrel crystal faces.

Plate XIII   Plate XIV

Plate XIII   Photomicrograph of botryoidal magnetite showing
                  fine bands. The black band is a layer of calcite.
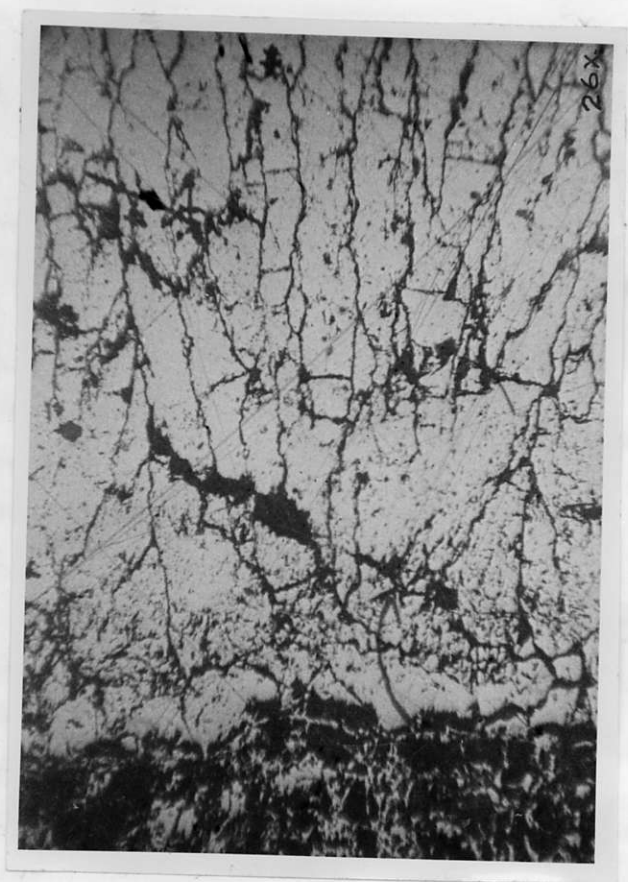   26 X.

Plate XIV   Coarsely crystalline outer band of botryoidal mag-
                  netite. The magnetite crystals are elongate and
                  arranged in a pallisade orihtation, perpendicular
                  to the concentric bands.

Plate XV

Plate XV   Polished section of botryoidal magnetite showing
            pronounced concentric structure and many irregular
            synresis or dehydration cracks.

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