STRUCTURAL GEOLOGY OF EMPIRE MINE

EMPIRE DEVELOPMENT COMPANY LIMITED

PORT MCNEILL, B.C.

by

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B.Sc., University of British Columbia, 1962

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science

in the Department of Geology

We accept this thesis as conforming to the required standard.

THE UNIVERSITY OF BRITISH COLUMBIA

March, 1966
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Date April 28, 1966.
Looking southwest to the Merry Widow Pit and waste dump from the Shamrock Zone.

(Photo by J. Lamb)
Foreword

Empire mine has been described by Jeffery (1960), Wittur (1961), Sangster (1964) and briefly by Eastwood (1965). Each of these writers has dealt essentially with general geology, mineralogy, geochemistry and ore genesis. Prior to this thesis no detailed examination has been made of structures and their relation to ore deposition.

Regional geology is based in part on work by Dr. W. G. Jeffery and in part on personal observations, as assistant to Dr. Jeffery in field seasons of 1960 and 1961 and as geologist for Empire Development Company Limited since 1962.

Both Merry Widow open pit and underground workings were re-examined, where possible, with special emphasis on structural relations. This work was supplemented by Company maps and reports by J. Lamb and the author.

It is hoped that this thesis may provide answers to at least some of the structural problems and possibly emphasize the importance of structural control in ore deposition.
Abstract

Empire mine is located on north-central Vancouver Island about two miles south of Benson Lake. Orebodies are typical of the many contact metasomatic iron deposits of the West Coast of British Columbia. They occur in Bonanza volcanic rocks and Quatsino limestone of Upper Triassic age near the margins of a small granitic stock of intermediate composition.

Structural controls at Empire mine are in part the configuration of the intrusion contact and in part the intersection of steep northeasterly faults with (a) folded and fractured volcanic rocks at the Merry Widow deposit and (b) with swarms of northwesterly striking greenstone dykes in the Kingfisher deposits. The Kingfisher fault transects both the Merry Widow and Kingfisher orebodies as well as the West Pipe and is considered one of the main channels for mineralizing solutions.

Relatively intense folding occurs near margins of the Coast Copper stock. In the Merry Widow area, plot of poles to bedding on Schmidt equal area net indicate a north-northwesterly plunging major fold. Superimposed on this are minor drag and disharmonic folds. Fold axes all strike northerly sub-parallel to the intrusion contact and folding is considered a direct response to emplacement of the Coast Copper stock.

Relation between intrusive greenstone and local folding would suggest that final stages of Bonanza volcanism, regional folding and emplacement of the stock with local folding and mineralization may be nearly contemporaneous.
Acknowledgments

The author wishes to extend his gratitude to all who have contributed to the preparation of this thesis, especially to Empire Development Company Limited for making this study possible. Thanks also to J. Lamb, Chief Geologist of Empire for many discussions on the geology and structural problems of the mine.

Assistance received from Dr. W. H. White in preparation of the final manuscript is greatly appreciated.
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D Plan of the Kingfisher adit (1920 level)
CHAPTER I  INTRODUCTION

First outcrops near Benson Lake were discovered in 1911 on what is now part of Coast Copper Company property. Following this first discovery several groups of claims were staked including those held at present by Empire Development Company Limited. Between 1911 and 1928 most of the Crown Granted Claims were located. In 1929 Quatsino Copper-Gold Mines Limited was formed and between 1929 and 1931 carried out limited exploration for copper. During this period Coast Copper Company was actively developing the Coast Copper Mine. In 1931 both companies suspended operations. In 1950 Japanese firms expressed interest in British Columbia iron and Quatsino Copper-Gold Mines Limited resumed exploration, only this time for iron. Massive magnetite was discovered in both Merry Widow and Kingfisher zones. In 1956 Empire Development Company Limited was formed to operate the newly developed mine and in September, 1957, production had begun from Merry Widow orebody. To date about 3,000,000 long tons of ore have been mined from Merry Widow, Kingfisher and Raven zones.

Location and Access

Empire Mine on north central Vancouver Island is two miles south of Benson Lake (50°127'E) and eighteen miles southwest of Port McNeill. Port McNeill is a small logging-mining community on the east coast of Vancouver Island served by highway from Campbell River ferry service from Kelsey Bay and daily plane service from Vancouver. Airport is twelve miles
north of Port McNeill. An all-weather gravel road extends from the mine to Port McNeill, a distance of twenty-five miles.

Physiography and Climate

Topography is moderately rugged. It is marked by wooded hills with many bluffs and steep-walled canyons. Relief in the area is about 3800 feet, that near the mine about 2100 feet. Mountains are mostly rounded hills with few ridges above tree line. Highest peak is Merry Widow mountain (el. 4600 feet). Benson River follows a crooked course in a flat narrow valley.

Climate is mild and wet. Maximum temperature recorded at Benson Lake is 100°F, minimum 2°F. Average temperature is 48°F. Annual precipitation exceeds 140 inches, most of which falls between October and May. Summer months can be pleasant.

Mild wet climate produces abundant vegetation. Area is timbered by hemlock, cedar, Douglas and balsam fir with occasional yew trees. Dense underbrush in lower areas forms an almost impenetrable jungle.
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**STRATIGRAPHIC CHART**

**Fig. 2**

- **Bonanza Group:** Volcanic flows of andesite and basalt, pyroclastics.
- **Quatsino Formation:**
  - **Argillite**, impure limestone
- **Karmutsen Group:**
  - **Basaltic and andesitic flows**
  - **Some pyroclastics**
CHAPTER II  REGIONAL GEOLOGY

Rocks of the Benson Lake area are shown on stratigraphic chart on Page 3. The greatest part of the region is underlain by rocks of the Vancouver group. These consist of great thickness of volcanic flows, pillow lavas, and fragmental rocks with interbedded limestones, limey argillites and argillites, cut by many dykes and irregular masses of greenstone. All members of the Vancouver group have been intruded by granitic rocks believed related to Coast Range Intrusions.

Vancouver Group

Karmutsen Group

Lowermost unit in the Vancouver group is the Karmutsen group. It consists of massive andesitic and basaltic flows, pillow lavas, with thin interbedded discontinuous sedimentary units. Upper horizons have been dated as Upper Triassic (Hoadley, 1953). Poorly preserved fossils collected by the writer from a sedimentary unit believed well down in the Karmutsen group have been sent to the Geol. Survey of Canada for possible identification.

Thickness of this unit is not known but is believed to exceed 10,000 feet. Surdam (Personal communication) suggests the thickness may be nearer 16,000 feet.

Upper Karmutsen rocks underly much of the area east of Empire mine. These are green, dark green and purplish amygdaloidal volcanic
flows, andesitic and basaltic in composition. Well-formed pillow structures are exposed in road cut near Maynard Lake east of Empire Mine.

Quatsino Formation

Quatsino formation conformably overlies Karmutsen rocks. It consists of white, grey to blue crystalline limestone generally massive in lower but commonly distinctly bedded near upper horizons. Bedding is marked by colour banding and thin siliceous bands as well as bedding planes or surfaces. Beds range from less than six inches to over six feet in thickness. Age of Quatsino limestone is Norian (Jeffery, 1960).

Quatsino limestone underlies an area immediately east of the mine and extends in a north-northwesterly and south-southeasterly direction. Area underlain by limestone is characterized by sinkhole topography and a noticeably less dense growth of underbrush than is typical of areas underlain by rocks of other types.

Bonanza Group

The Bonanza group forms the upper part of the sequence and lies conformably on the Quatsino formation. It is predominantly volcanic rock with a small sedimentary unit near the base. This sedimentary unit is not present everywhere in the region.

Volcanic rocks consist of tuffs, agglomerates volcanic breccias, with some lava flows. Tuffs, in some areas well-bedded, vary from fine-
to coarse-grained and are predominantly brown, green or greenish-grey in colour. Agglomeratic rocks vary from fine- to coarse-grained, with fragments ranging in size from 1/4 inch to one foot. The term agglomerate here is applied to most of the coarse pyroclastic rocks.

A rock with a limestone matrix and volcanic fragments occur at the base of the volcanic unit in some places. Hoadley (1953 p 23) has termed a similar rock in the Nimpkish - Zeballos area an agglomeratic limestone. Flow rocks are not abundant but occasionally occur interbedded with tuffs and agglomerates. An occurrence of an amygdaloidal feldspar porphyry flow rock is exposed southwest of the mine near Rainier Creek. This rock type is not common.

West of the Empire mine on the south slope of what is locally known as "Little Merry Widow" mountain, is an occurrence of a distinctive spherulitic lava. On a weathered surface these spherulites stand out as rounded grey nodules, one quarter to slightly over one half inch in diameter. Spherical forms comprise about 75% of the rock. The spherulitic unit is from three to six feet in thickness, intercalated with finely banded volcanic rocks, possibly acidic flows. Gunning (1929 p 102A) briefly mentions spherulitic beds on Merry Widow Creek, referred to then as Bean Creek.

Sedimentary rocks of the Bonanza group are exposed south of Empire mine. They consist of thin bedded impure carbonaceous limestones, black calcareous argillites, argillites, and tuffaceous argillites. The underlying Quatsino formation grades sharply into Bonanza sediments and the boundary between the two units is an arbitrary one. (Hoadley 1953 p 20)
defines the boundary as the horizon in which change from predominantly calcareous to predominantly tuffaceous rock occurs.

Bonanza rocks cover an area southwest and west of the mine. The top of the sequence does not occur in the region and thickness is not known. It is at least 3,200 feet thick. (Hoadley 1953 p 22).

Intrusive Rocks

A crystalline igneous body, known as the Coast Copper stock, intrudes the Vancouver group rocks west of Empire mine. It is part of the Island intrusions believed related to Coast Range intrusive complex, and emplacement, therefore, was Upper Jurassic or Cretaceous time. It is composed of two distinct rock types, diorite-gabbro and monzonite. These are very likely genetically related.

Diorite-gabbro occurs nearest the mine. It is largely diorite with gabbroic phases along the easterly and northeasterly margins. It is white to grey in colour with the more gabbroic rock being dark greenish-grey. Remnants of metamorphosed Bonanza rocks are included within the stock.

West of the diorite-gabbro and partly separated from it by Bonanza volcanic rocks, is a small northwesterly trending mass of pink to pinkish-brown monzonite. Zenoliths of diorite in the monzonite suggest later intrusion of the monzonite.

The stock is about 1½ miles wide and 3½ miles long, elongate in a northerly direction.
The Vancouver group is cut by a host of dykes, sills, and small irregular-shaped masses of greenstone. These intrusions vary in composition and texture but are essentially fine-grained greenish andesite, very easily confused with extrusive rocks of Karmutsen and Bonanza groups which they invade. Jeffery (1960) and Hoadley (1953) have suggested that these greenstones are genetically related to Bonanza volcanism.

Structural Geology

Rock units mapped to southeast and northwest of Empire mine, not affected by possible disturbance during emplacement of Coast Copper stock, have a persistent northwesterly-southeasterly strike and southwesterly dip. Jeffery (1960) has described these units as forming part of a southwesterly dipping monocline. Eastwood (1963) reports rocks resembling Karmutsen in character near Power River, 16 miles southwest of Empire mine. He has also noted a limestone unit, much thinner than Quatsino, overlain by rocks resembling those of Bonanza group. It is probable that rocks mapped in the Empire area form the eastern limb of a broad syncline folded about a northwesterly trending axis.

Bedded Quatsino limestone strikes northwesterly and dips southwesterly at 25° to 35°. Small variations in strike and dip reflect gentle flexures. Immediately east and extending along the Coast Copper stock, limestone strikes northerly, generally parallel to the axis of elongation of intrusion. At the north end of the stock it swings sharply northwest. At first glance the sharp change in strike appears to mark the
nose of a southwesterly plunging syncline with Coast Copper stock intruded into this nose. Change to a northerly strike is confined to rocks adjacent to and east of Coast Copper stock. It is likely that this change in strike is due in part to intrusion of the stock. This stock, therefore, is not intruded into the nose of a southwesterly plunging syncline (Sangster 1964 p 185) but rather the rocks are deformed as a result of the intrusion. Where the intrusion has invaded volcanic rocks, these have only been mildly deformed. Where limestone is in contact with the intrusion, folding is more pronounced. In Craft Creek Quatsino limestone is folded into isoclinal folds against Coast Copper stock.

Faulting is prevalent in three sets: northwesterly, northerly and northeasterly faults. Northwesterly faulting is more prevalent in the Alice Lake area northwest of Empire. Here, along a ridge between Neroutsis Inlet and Alice Lake, a prominent northwesterly fault has thrown Quatsino limestone against Cretaceous sandstones (Jeffery 1962). Northwesterly faults near Empire mine show little or no displacement. The valleys of Kwois Creek to the south, Benson River, Maynard and Three Isle Lakes, east of the mine, form a prominent north-south topographic lineation that may reflect north-south faulting.

North-striking Benson River fault, east of Empire mine, has a left lateral displacement of one mile and a dip slip component of movement estimated as 4,000 feet. Faults repeat Quatsino limestone to the east. Northeasterly faults near the mine show small displacements only. Rainier, Merry Widow, South and Marten Creeks are expressions of northeasterly faults. These cut Quatsino limestone and Bonanza rocks as well as those of Coast Copper stock.
CHAPTER III LOCAL GEOLOGY

Magnetite at Empire mine occurs in limestone and volcanic rocks near the margin of the Coast Copper stock. The Merry Widow and Raven deposits are in a small wedge of volcanic rocks, the Kingfisher completely within limestone. All are near the upper contact of Quatsino limestone. Geology at Empire mine area is shown on Map A (in pocket).

Bedded Quatsino limestone strikes northerly and dips westerly at moderate angles toward the stock. Strike generally parallels intrusive contacts. Local variations in attitudes reflect gentle open folds. Most prominent change in strike occurs near a bulge in the Coast Copper stock north of Empire mine. Intensity of deformation increases toward intrusive contact. Near Merry Widow deposit, limestone dips steeply to the east; to the north near the Shamrock and Blackjack showings, limestone dips steeply near intrusive contacts. In Craft Creek limestone in contact with the intrusion is isoclinally folded about a west-northwesterly axis.

Bonanza rocks overlie the limestone and occur as a discontinuous rim around margins of the Coast Copper stock. North of Empire mine, rocks previously mapped as Bonanza volcanics are not considered part of extrusive Bonanza rocks, but rather one of the many greenstone masses found near the mine. If these are Bonanza rocks there is a stratigraphic problem. Limestone at the Merry Widow deposit is nearly 4,000 feet thick, near Blackjack and Shamrock, 3,000 feet. At the bulge in the stock, between the Blackjack and Merry Widow, it is 1,600 feet thick. There is 1,400 feet of Quatsino limestone missing in this section. There is no evidence to suggest that
this amount of limestone has been displaced by faulting. It is suggested
on this basis that these rocks are part of the many intrusive greenstone
masses common near the mine.

Bonanza rocks consist of metamorphosed tuffs, flows and agglomerates. Bedding is poorly preserved but where visible conforms to the
generally northerly trend and westerly dip. Massive rocks are fine-grained,
dense, medium to dark green in colour, indistinguishable from intrusive
greenstone which invade them. On the northwest and westerly wall of the
Merry Widow pit, bedding is preserved as colour banding. Banding is due
to segregation of light and dark minerals; light bands are predominantly
feldspar, dark bands pyroxene. Result is a gneissic texture. Jeffery
(1960 p 95) calls this rock a pyroxene-plagioclase gneiss. Colour banding
is thought to reflect original bedding in volcanics.

The Coast Copper stock intrudes both limestone and volcanic rocks.
Contacts are generally steep, ranging from 70° to almost vertical. Near
Merry Widow pit underground development and deep drilling show the contact
near surface to dip at about 55°, steepening to near-vertical at a depth of
650 feet below floor of Merry Widow pit. The effect of thermal metamorphism
on limestone has been re-crystallization. Volcanic rocks near the intrusive
margin are in part hornfelsic and in part "granitized." Rocks referred to
as "granitized" are essentially those in which metasomatism has in effect
produced a feldspathic rock, in places resembling an altered diorite. Areas
of feldspathization are irregular, generally less than 10 feet in diameter
and grade out into massive metamorphosed volcanics. This is most noticeable
in Merry Widow pit where metasomatism has had its greatest effect.
Intrusive greenstone, commonly regarded, at least in part, as intrusive phases of Bonanza volcanism, form large irregular masses, dykes and sills. They are dense, fine-grained, greyish-green to dark green rocks, mostly andesitic or dacitic in composition. The largest greenstone mass is andesite.

Faulting is prevalent near the mine. East to northeasterly faults are numerous, and bear close spatial relation to ore deposits. These are prominent faults with a steep southerly dip. Movement has been negligible. Most can be traced into intrusive diorite and have post-intrusive movements. Northerly faults, one which follows in part the Merry Widow Creek, another the Benson River, have repeated outcrops of Quatsino limestone to the east.

Movement along bedding planes is recognized in both limestone and volcanic rocks. In the Kingfisher pit, movement along the base of a westerly dipping (20 - 25°) greenstone sill is recognized by gouge and slickensides, indicating reverse movement. Fragments of the skarny greenstone sill, with selvages of magnetite and chlorite are healed by coarsely crystallized calcite. The inference is that the fault is a pre-mineral break in which movement had continued during mineralization, fracturing early formed magnetite which was later healed by coarse crystalline calcite. Magnetite and calcite occur in a similar relation in the footwall. Magnetite has spread out under the sill suggesting that the sill, in part, served as an impounding structure to mineralizing solutions.

Movement has occurred in volcanics along bedding planes (fig. 3, p 13). Angular fragments of volcanic material, healed predominantly by
Fig. 3

Sketch to illustrate the nature of brecciation along bedding planes in Bonanza volcanic rocks.
pyroxene, form lenses of breccia along bedding planes. Fragments show a general alignment parallel to bedding.

Petrology

Petrology is based on a study of eighteen thin sections taken from rock types which might have a direct bearing on structural interpretation. Jeffery (1960), Wittur (1961), Sangster (1964) and Eastwood (1965), have ably described common rock types and duplication of this work was not warranted. Four specimens of greenstone, including one from a large irregular mass near Kingfisher pits and three from dykes exposed underground, were examined petrologically to determine the variation in composition. Specimens from spherulitic lava, acidic dykes, breccia, banded volcanics, feldspar porphyry and limestone were also examined. Two sections across contacts between dark siliceous beds and limestone, were examined for any evidence of bedding plane movement. Each of these are described briefly below, supplemented to some extent by descriptions by early workers.

Spherulitic Lavas

A small unit of spherulitic lava outcrops west of Empire mine in a small gully on the south slope of what is known locally as "Little Merry Widow" mountain. The unit, three to six feet thick, crudely banded, is intercalated with thin-banded volcanic rocks, possibly acidic lavas.
The rock is composed of spherical forms that range in size from 1/4 to 1/2 inches in diameter, cemented in a green aphanitic matrix. The spherical forms have a radiating structure. Finely disseminated magnetite is distributed throughout both matrix and spherulites. The ball-like forms weather out like marbles. (Plate I p 44)

Rock consists of radiating masses of albite feldspar with interstitial quartz. Polysynthetic twinning is not common. X-ray powder photographs confirm albite and quartz. Albite is slightly cloudy, crystal boundaries are not distinct. Quartz is clear. Mafic minerals are almost completely lacking, less than 1% chlorite is present as the only mafic mineral. Magnetite is lathlike and short stubby crystals form irregular patterns crossing spherical form boundaries without interruption. Structures along which magnetite crystals have formed may be simultaneous with or later than the formation of spherical forms, depending on which origin of spherulitic lavas is accepted. Possible origins of spherulitic lavas are: (a) immiscible liquids; (b) devitrification of glass; (c) rapid crystallization of a viscous lava. Spherulitic lava near Empire mine is believed formed by devitrification of volcanic glass.

Bonanza Volcanics

Bedded volcanics are best exposed on the northwest rim of the Merry Widow pit where bedding is preserved as colour banding. (Plate II p 45) Rock consists of light and dark alternate bands, some bands coarsely crystalline. Lighter bands consist of predominantly plagioclase, and dark bands pyroxene. Modal analysis is 47% plagioclase, 20% pyroxene
with less than 10% K-feldspar. Alteration minerals include ragged amphibole (actinolite) laths, epidote, calcite, chlorite, with accessory sphene. Prehnite forms clear crystals in lighter bands. The rock has been called a pyroxene-plagioclase gneiss by Jeffery (1960).

**Diorite-Gabbro**

Diorite is a light grey to greenish-grey, medium- to coarse-grained granitic rock. Gabbroic phases are darker in colour and contain a higher percentage of mafic minerals and magnetite than diorite. Analysis by Sangster (1964) shows the basic border zone, to a distance of 800 feet into stock, to contain an average of about 8% iron. Modal analysis of gabbro by Sangster (1964) is 50% plagioclase (An53), 39% augite, 7% actinolite, 2% opacite and 2% accessories.

**Breccia**

Near the diorite intrusive contact, exposed only in underground workings on the main haulage level, is a breccia zone 120 feet across separating diorite from the limestone. The rock has three distinct textures; (a) fragmental rock composed of dark greenish-grey angular to sub-rounded rock fragments in a light grey to pinkish groundmass, (b) a less marked fragmental rock with clusters of mafic minerals and knots of garnet in a fine pinkish-grey groundmass, and (c) a "mylonitic" rock with augen-like clusters of pyroxene. The latter rock has a marked lineation (Plate XII p 55).
The first rock type consists of rock fragments composed of anhedral grains of feldspar with 25% equant intergranular pyroxene. Clusters of larger pyroxene occurs in inter-fragment spaces. Epidote, sphene and prehnite fill fractures. Zoisite, clinozoisite (x-ray confirmation) and carbonate also occur as alteration minerals.

The second type consists of 21% albite (Ang_11) and 50% K-feldspar with interstitial equant grains of augite. Clusters of larger anhedral augite grains have a tendency to be augen or lense-like. Small equant and irregular yellowish-brown isotropic garnet rarely showing crystal form, bears a close spatial relation to pyroxene. Late minerals filling fractures include calcite, K-feldspar, epidote and prehnite; apatite and chlorite occur sparingly. Fine-grained nature of rocks prohibits accurate determination of feldspars. Etch tests with HF and sodium cobaltinitrate suggest preponderance of K-feldspar. X-ray powder photographs and optical properties confirm pyroxene as augite.

The third type is much the same as the second. Pyroxene forms lense- or augen-shaped clusters with lineation near vertical. Specimen examined came from near light coloured greenstone dyke that cuts the breccia zone.

Intrusive Greenstone

Greenstone masses, dykes and sills are predominantly andesitic in composition. Of the four specimens examined, three were andesite and
one was "dacite." All had suffered some alteration, and with the exception of the "dacite," all had selvages of skarn and, in part, magnetite along the contacts.

**Andesite:**

Most prominent dyke underground is a large andesite dyke 35 - 40 feet in width that has been emplaced or at least lies along the main thrust fault that cuts into the Merry Widow pit. The dyke strikes northerly and dips at about 55° easterly. Closely spaced joints are filled with pink K-feldspar, epidote and brown garnet. Sub-parallel fractures and alteration haloes give the rock a banded appearance. The dyke is referred to as the "West Pipe" dyke.

The specimen consists of a felted mass of feldspar microlites with intergranular equant pyroxene. Occasional untwinned feldspar phenocrysts, considerably altered to sericite and epidote are present. In one instance a feldspar crystal is completely altered and replaced by a mosaic of anhedral epidote grains. Both epidote and feldspar are cut by calcite veinlets. Epidote fills fractures, decreasing outward from the centre.

Modal analysis shows the rock to consist of 43% plagioclase (An50), 15% K-feldspar and 18% pyroxene (augite) with sphene and apatite as accessories. Alteration minerals include K-feldspar, epidote, calcite, diopside, garnet and prehnite. Opaque minerals include a few scattered grains of pyrite, magnetite and chalcopyrite.

Other dykes examined are similar in character to that described above. A 10-inch dyke consisted of large remnant grains of pyroxene cut by laths of plagioclase in subophitic relation. Sericite, epidote and
calcite alteration obscures original nature of feldspar. Untwinned anhedral K-feldspar comprises about 20% of the rock, plagioclase 25% and intergranular pyroxene 17%. Ragged laths of amphibole occur sparingly. Calcite prehnite and epidote occur as vein minerals. Texture was likely originally diabasic.

"Dacite":

A greenstone dyke cuts the breccia zone exposed on the 1920 level. It is a fine-grained, grey-green felsitic rock composed of 30% anhedral to subhedral plagioclase, 33% anhedral K-feldspar with 23% interstitial quartz, and 1% intergranular pyroxene. Biotite and amphibole comprise less than 1%. Calcite, epidote and chlorite occur as alteration minerals; accessory minerals are apatite, magnetite and pyrite. Pyroxene, in part, forms clusters of anhedral grains. Quartz and K-feldspar are at least in part introduced or metasomatic, hence original nature of rock is obscured.

The dyke is cut by irregular masses of fine-grained granite which enclose angular fragments of the intruded rock.

Granite Dykes:

In underground workings cutting breccia is a grey to pinkish-grey, fine crystalline igneous rock with a composition of granite. It is composed almost entirely of large anhedral to subhedral K-feldspar and quartz. Modal analysis shows 60% perthitic feldspar, 35% quartz and 4% aegerine-augite with apatite and sphene as accessories. Jeffery (1960) describes an alaskite north of the Kingfisher pit. Near this latter occurrence, greenish-grey, medium-grained andesite is cut and brecciated by fine-grained granite. Edges of brecciated fragments are bleached by
granite. Only mineralogical change in the bleached haloes is a reduction in amount of opaque iron minerals.

Feldspar Porphyry:

Sutherland-Brown (1962) has pointed out the ubiquitous relation between feldspar porphyry dykes and contact metasomatic deposits associated with Vancouver group rocks.

North of the Kingfisher pit, cutting brecciated intrusive andesite is a feldspar porphyry dyke which in turn is cut by later granite dykes (alaskite). It is a dark green, fine-grained rock with laths of plagioclase showing a sub-parallel alignment with dyke contacts. Laths range in size from 3mm to 7mm. It consists of large phenocrysts of plagioclase (An56) enclosed in a felted mat of feldspar microlites with intergranular pyroxene. Epidote and calcite occur as alteration minerals along corroded feldspar grain boundaries, cleavage planes and fractures. Some feldspar are zoned, some not; all show undulatory extinction. Few ragged biotite flakes and amphibole laths occur sparingly, biotite is closely associated with pyrite.

Post Ore Basic Dykes:

In the Merry Widow and Raven ore zones, are post-ore green dykes with a coarse, sugary texture. They cut andesite dykes, ore zones and gabbro and are likely one of the latest phases of intrusion. They vary little from andesitic dykes in composition, containing 37% plagioclase, 8% K-feldspar, 25 - 30% pyroxene, 12% chlorite and 3% epidote. Long laths of plagioclase and subhedral pyroxene with interstitial chlorite form most of the slide. Pyroxene is replaced in part by calcite and in part by a
brown fibrous mineral exhibiting radiating forms. An undetermined mineral, brownish green in colour, slightly pleochroic, forms radiating masses with striking birefringent colours. It is a minor alteration mineral.

Gunning (1929 p 107A) in reference to acidic, basic and porphyry dykes found near stocks, states "--- they are believed related in origin to main intrusive bodies in that they represent differentiates from the same parent magma".

**Metasomatic Vein Rock:**

On the north wall of the Merry Widow pit volcanic rocks appear cut by a finely crystalline rock which shows crosscutting relations to bedded volcanics and in many respects is dyke-like. Contacts are relatively sharp and the vein in places includes fragments of wall rock in which bedding in fragments matches that in wall rocks.

The vein rock is light grey, slightly mottled, spotted with small clusters of pyroxene. It consists of large altered feldspar crystals studded with anhedral pyroxene set in a groundmass of equant plagioclase feldspar and granular pyroxene. Plagioclase for the most part does not show multiple twinning and all are unzoned. Determination of feldspars by Michel-Levy method and refractive indices indicates a composition of at least An$_{32}$. Pyroxene (augite) forms clusters of clear crystals as well as equant grains which commonly have an alteration halo. Composition of the rock is approximately 70% plagioclase, less than 5% K-feldspar and 25% pyroxene (augite) with less than 3% epidote, sphene and apatite.

Vein is considered to be a metasomatic rock in which metasomatism
has occurred along fracture systems and bedding surfaces, producing intrusive-like characteristics (Plate II p 45).

**Siliceous Bands in Limestone:**

Within Quatsino limestone are thin siliceous bands that range in thickness from a fraction of an inch to three inches. They are extremely fine-grained and finely banded, dark, slightly calcareous rocks with finely disseminated pyrite. Microscopic examination shows the rock to consist of about 15% pyrite with scattered quartz grains in a fine dark brown groundmass. With the exception of pyrite, quartz and occasional carbonate grains most of the groundmass could not be identified. Contacts with limestone are sharp. Adjacent to the contacts limestone has a fine granulated texture in which occasional fragment of coarse calcite is enclosed in the finer material. Relation indicates movement along bedding planes on an extremely fine scale.

**Ore Zones**

Most of the production from Empire mine came from the Merry Widow and Kingfisher deposits. Approximately 20,000 tons of ore was taken from the Raven zone in 1960 but sulphide content was particularly high and the pit was abandoned. Since then it has been buried by waste. Description of the Raven zone given here is from company reports. Geology of ore zones is shown on Map B (in pocket).
The Merry Widow orebodies occur as tabular-shaped masses with irregular boundaries within a wedge of meta-volcanics of the Bonanza group. This wedge is bounded to the west by the easterly dipping gabbro and to the east by westerly dipping limestone. Width decreases sharply with depth to 150 feet where it is exposed underground as a severely brecciated skarny rock. It is separated from gabbro by 15 feet of massive garnet-epidote skarn and from limestone by 10 feet of massive skarn. Diamond drill data indicates an irregular volcanic-limestone contact dipping toward the gabbro. Contact curves sharply down toward the gabbro. Intrusive contact in the pit dips easterly at 55°, steepens to 70° or 75° below the 1920 level. Magnetite layers lie parallel to the contact.

Ore occurs as massive magnetite, replacing both skarn and volcanic rocks and partially enclosed by a halo of garnet-epidote skarn. Replacement is incomplete and orebodies may have lenses of low grade to barren skarny rock interlayered with ore-grade material.

The Merry Widow deposit may be divided into three units; an upper, intermediate and a lower unit. The upper unit is a tabular body 340 feet long by 500 feet thick plunging eastward at 30°. Ore terminates abruptly down plunge against limestone. Upper termination grades sharply into skarny volcanic rocks. Lying below and separated from it by about 40 feet of relatively barren mixed skarn and volcanic rocks, is the intermediate unit. It is tabular in shape, has a length of 280 feet, thickness of 30 feet and lies parallel to the upper unit. The main thrust fault extends between these two orebodies, cutting the barren rocks. Footwall rocks have been
folded upward against the fault as evidence of reverse movement (fig. 4 p 25). The third and lowermost unit lies along the gabbro contact, separated from it in most places by a cushion of skarn. Down dip extent, defined by limits of exploration, is 540 feet, maximum thickness is 140 feet. It tapers with depth. Where the intrusive contact steepens, ore layers also steepen and at one point ore occupies an enclave in the gabbro, reflecting the close relation between configuration of gabbro contact and orebody. There is little doubt but that the form of the deposit is to some extent controlled by the intrusive contact.

Mineralization consists of massive magnetite with associated pyrrhotite, pyrite and chalcopyrite. Other minerals found include cobaltite, arsenopyrite, sphalerite, erythrite and chalcotricite. This last group is found in small or trace amounts. X-ray powder photographs confirm chalcotricite (cuprite). Sulphides are discussed in another section with relation to zoning.

Colloform magnetite from the Merry Widow pit has been described by Stevenson and Jeffery (1964). Formation of botryoidal forms has been ascribed to crystalization from colloidal suspension under relatively low pressures. Curvature of the forms is convex against white calcite and magnetite shows both radiating and concentric growth to botryoidal forms. Sangster (1964) has discussed possible origin of colloform magnetite and concluded that magnetite in Kingfisher deposit was deposited from a colloidal dispersion by re-deposition of earlier magnetite in a post-ore fault now cemented by calcite. The solutions which carried this calcite dissolved some of the crystalline magnetite of the brecciated ore in the
Sketch showing the drag effect in volcanic rocks as a result of reverse movement on an easterly dipping fault.
fault and this dissolved magnetite was precipitated both as an electrolytic crystalline aggregate and also as a colloid. Skarn minerals include andradite-grossularite garnet, diopside, actinolite, epidote, pink K-feldspar and calcite. Clear calcite rhombs have been found in a partially filled cavity with associated small well formed prisms of ilvaite and cubes of pyrite.

Kingfisher

The Kingfisher has two steeply plunging cylindrical or pipe-like orebodies that merge with depth. Both lie within Quatsino limestone, approximately 1000 feet from the gabbro contact. Maximum vertical extent of the two pipes is 420 feet. They taper and finger out into limestone with depth. Magnetite is massive forming sharp contacts with limestone. Skarn minerals are confined to many greenstone dykes and sills criss-crossing the ore. Skarn forms selvages along greenstone dykes and sill contacts and in part replaces large areas of the original rock. Magnetite penetrates greenstone to some extent but has favoured limestone. Replacement of limestone has been such that original bedding is preserved in magnetite (Plate III p 46).

Limestone has been folded into gentle flexures, nowhere are the rocks intensely deformed. Swarms of greenstone dykes and at least one prominent sill cuts both pipes. The Kingfisher deposit lies between two greenstone masses, one 400 feet to the southeast, the other 800 feet to the northwest, with the swarms of pre-ore dykes between. The sill exposed in the Kingfisher East dips at 25° westerly. Reverse movement has occurred
along the base of the sill. Magnetite has moved out along the base of the sill which has acted as a barrier, suggesting that mineralizing solutions were ascending.

The steep northeasterly-trending Kingfisher fault cuts both deposits. The intersection of the Kingfisher fault, with greenstone dykes and sills, is believed to provide favourable sites for deposition.

Raven Zone

The Raven orebody lies at the southwesterly end of a long northeasterly trending zone of mineralized greenstone associated with a northeasterly trending fault. It consists of magnetite with associated sulphides, pyrrhotite, pyrite, sphalerite and chalcopyrite. The orebody occurs as a tabular mass surrounded in part by massive garnet and epidote skarn and plunges steeply to the southeast. High sulphide content made the deposit uneconomic and after extracting about 20,000 tons of ore the deposit was abandoned.

West Pipe

In early exploration, a magnetic high was obtained west of the Kingfisher central deposit and was named the West Pipe. Diamond drilling has indicated the existence of mineralization but not enough to make an orebody. Mineralization consists of massive magnetite as a tabular body immediately overlying the West Pipe dyke. Its occurrence coincides with
the intersection of the dyke and the Kingfisher fault. Small lenses of pyrrhotite, pyrite, arsenopyrite and chalcopyrite with associated gold in calcite gangue lie along the hangingwall of the West Pipe dyke.

**Zoning**

Within the Merry Widow and particularly in the Raven zone, magnetite has associated with it pyrrhotite, pyrite and chalcopyrite. Sulphides occur as small masses, commonly associated with white calcite and as disseminated grains distributed throughout the massive magnetite. Pyrrhotite is most abundant. Ratio of sulphides to oxides in general increases with increased distance from the gabbro toward the limestone contact. Closely spaced test holes in the Merry Widow pit between elevation 2260 and 2220 were sampled at 10 feet intersections during mining. Copper content of the 10 foot intersections has been plotted on plans for the 2260 and 2220 levels to show relation to magnetite. Results indicate that sulphide concentration is peripheral to massive magnetite. Greatest concentration is along the northeastern margin of the Merry Widow orebody (fig. 5 and 6 pp 29 and 30). Occurrence of sulphides is erratic and a continuous zonal arrangement could not be established.

**Greenstone Relation**

A significant feature at Empire mine is the presence of irregular masses, dykes and sills of what is known at Empire as "intrusive greenstone." Megascopically and microscopically, these are all similar. With
Merry Widow Pit
el. 2260
Copper Distribution
> 1% Cu ---
0.5-1% ---
0.1-0.5% ---
< 0.1% ---

Fig. 6
Scale: 1" = 40'
some exceptions, most have intergranular texture, in part diabasic, consisting of a felted mass of feldspar microlites with intergranular augite. Feldspar in one dyke showed subophitic relation to pyroxene. Chlorite and epidote alteration is common.

The larger masses shown on Map A (in pocket) are dark green to grey-green aphanitic rocks with little variation in texture. Contacts are generally steep and in places, show fault contacts with limestone. Intrusion has produced some bleaching of limestone, but little evidence of deformation. Commonly associated with these greenstone masses are small deposits of magnetite. Associated with some but not all deposits, are northeasterly trending faults.

Greenstone dykes invariably have selvages of skarn and/or magnetite along margins which may project into limestone. There is little doubt that these dykes are pre-ore and have served, in part, as guides to metasomatizing solutions. Greenstone dykes are cut by granitic rocks thought to be related to the Coast Copper intrusions and are, therefore, probably pre-intrusion.

Relation of greenstone to folding is not so clearly defined. Configuration of some dykes and their relation to limestone suggest possible intrafold emplacement. Some of the relations observed are:

1) A broken dyke with fragments displaced by movement or adjustment within limestone may occur within 10 feet of a similar dyke which remains intact, undeformed (Plate X p 53).
2) A greenstone sill following the crest of a gentle open fold has been cut by a later dyke with a slight displacement on the limestone (Plate XI p 54).

3) A greenstone sill, 3 to 4 inches thick, fragmented with small displacement of fragments, follows crest of a small fold. A similar sill follows over the crest of a small fold unbroken (Plate V p 48).

4) Dykes are commonly emplaced along axial surfaces of open folds.

5) Dykes side by side may have different contact relation. Narrow sill-like projections from larger dyke with ragged contacts are cut by later dyke with clean contacts and chilled margins (Plate VIII p 51).

6) Some small greenstone masses exposed underground have very irregular shapes with arm-like protrusions that suggests both rocks were "--- highly mobile."

Carlisle and Susuki (1965 p 464) describes similar relations at Open Bay on Quadra Island and conclude that "--- andesite pods and sheets are intrusive bodies, most of which were emplaced after an initial period of strong folding."

The writer suggests that in the Empire area, greenstone dykes are mostly pre-folding but that intrusion of greenstone continued into early stages of folding prior to or during emplacement of Coast Copper stock.
Structural Geology does not appear to be particularly complex.

Of the thirteen magnetite deposits associated with the Coast Copper stock, eight lie along northeasterly faults. The Kingfisher, Merry Widow, Raven, Shamrock and Blackjack lie in enclaves or re-entrants in the stock. Where these re-entrants have occurred, limestone has been deformed. All lie in or near greenstone masses or are cut by greenstone dykes, and where these intersect northeasterly faults, they provide favourable loci for deposition.

There is little surface indication of folding. The Quatsino limestone is relatively pure and contains no structures which might indicate tops or bottom of beds, hence presence or absence of overturned beds is based on interpretation of data.

Folds

Relict bedding in meta-volcanics near the gabbro contact, has a northerly strike and steep westerly dip. On the headwall of the Merry Widow pit, dip at the contact is from 80° westerly to vertical. The dip decreases with increase distance from the gabbro to a westerly dip of 25 to 30°. Change in dip defines the westerly limb of a northerly trending anticline. Where alteration is intense near the orebody, volcanic rocks have a hornfelsic texture and bedding is obscured by alteration. Poles to bedding, plotted on a Schmidt equal area net, lower hemisphere, form a broad girdle along a great circle defining a fold with axis at 354° and plunge 18° (fig. 7 p 34). Attitudes of beds (100 points) within the
Figure 7

Plot of poles to bedding in the Merry Widow area indicate a north-northwesterly plunging fold. Fold axis of measured folds are indicated by small \( \times \).
Merry Widow area only were used. Trace of the fold axis conforms generally to the gabbro contact. Underground development and diamond drilling outline an irregular but upfolded volcanic limestone contact, dipping westerly, thus supporting the surface evidence for folding (Map C in pocket).

Limestone near the surface expression of the limestone-volcanic contact has a steep easterly dip and north-northwesterly to northeasterly strike. Dips range from 60° to 85° easterly. At the entrance to Merry Widow pit, left wall, the western limb of an overturned fold can be traced. Axial plane strikes east of north and dips 55° easterly. (Plate IV p 47). To the right of the pit entrance limestone folds sharply down to the west. West of this point beds have a steep easterly dip and east of this point dips are 10 to 20° easterly. Axial plane dips easterly at 50 to 57°. In the main haulage level underground, east of the West Pipe dyke, limestone is sharply folded into an overturned anticline with strike of axial plane west of north and dip 57° easterly. West of this fold, limestone dips steeply and is intensely deformed. East of the fold dip of limestone is more gentle, deformation less intense. This fold is an underground expression of the fold indicated on the surface and the projected axial plane between them is sub-parallel to the West Pipe dyke. In the underground, the main thrust lies along the footwall of this dyke. The same stresses which caused the thrust movement also produced the overturned fold. Volcanic rocks were more resistant and small drag folding only occurred. In the Merry Widow pit, bedded volcanics are folded against the fault indicating a reverse movement with hangingwall rocks moving westerly relative to footwall rocks.
A third type of fold, seen only in underground, are folds of small amplitude generally 2 to 10 feet, occurring west of the West Pipe dyke. These are similar type folds with near-vertical to steep easterly dipping axial planes and northerly plunging fold axis (Plate V p 48). Observed relation to larger folds indicate that these occur principally on the western limb of the larger main fold.

Superimposed on bedding in the limestone are minor disharmonic folds with an amplitude of less than one foot. Fold axis may plunge either to the north or south but strikes generally within 10° of north. Axial surfaces are highly irregular, thin beds, inches apart, will have totally different configuration (Plate VIII p 51). Thin, brittle beds within limestone may be folded and broken with fragments displaced (Plate VI p 49).

During emplacement of the Coast Copper stock, limestones and volcanic rocks were locally folded about a northerly axis forming an asymmetric fold with steep easterly dipping axial plane. Superimposed on this main fold is a sharp overturned anticline in limestone folded against the West Pipe dyke. At some stage during this minor folding a break occurred along the base of the West Pipe dyke. Small reverse movement on the fault occurred accompanied by drag folding, both in limestone and volcanic rocks. Limestone responded to stresses by folding, the more brittle volcanic rocks by fracturing. Greenstone sills and dykes broken during deformation, form boudinage structure (Plate VII p 50). Limestone has moved in to fill space between fragments. Greenstone boudin commonly have a thin selvage or rim of skarn clearly showing that boudinage structure was formed prior to mineralization.
There is a close correspondence between attitude of axial planes which would suggest that these are related to one period of deformation. Folds are nearly parallel to the intrusive contact and are confined to a small area within an embayment in the Coast Copper stock. Relatively intense folding associated with orebodies at Empire mine is considered to be a direct response to intrusion of the stock.

Folding in the Kingfisher deposit is less intense than in the Merry Widow. In Kingfisher East, rocks are folded into a gentle northeasterly plunging anticline. In the Kingfisher Central, limestone is relatively undeformed, beds generally strike northeasterly and dip northeasterly.

Faulting

Faults occur in three sets: north trending steep normal faults, east to northeasterly high angle faults and northeasterly reverse faults with moderate easterly dips (50° - 57°). Three of the more prominent faults are discussed in some detail below.

Kingfisher Fault

The Kingfisher fault is not the most prominent fault exposed but is the most persistent, both laterally and vertically. It has been traced in the underground at all levels as a tight break, cutting the orebody. It is a northeasterly-striking fault with a steep southeasterly dip. Where
exposed on the headwall, it has a steep southerly dip which decreases sharply at the foot of the wall to about 69°, then increases to 80 or 85° in the bottom of the pit (Plate XV p 57).

The fault makes a broad swing to the northeast, maintaining a steep dip and extends through the Kingfisher Central and Kingfisher East orebodies. Where this fault has been observed underground, it has selvages of magnetite and/or skarn along it. Within the Kingfisher deposits, brecciated magnetite along the fault suggests post-ore movements. Also within the Kingfisher deposit magnetite apparently replacing limestone outward from the fault suggests a pre-ore break. The Kingfisher fault with a persistent lateral and vertical extent, is considered to be one of the more important controls in deposition in both the Kingfisher and Merry Widow deposits.

South Fault

Along the south wall of the Merry Widow pit is a prominent steep, rusty easterly-striking fault (see Plate XVI). Fault surfaces are lined by calcite crystals coated with a brown earthy mineral. Thickness of calcite filling is as much as 8 inches.

Main Thrust

The main thrust exposed in the Merry Widow pit strikes east of north and dips easterly at 50 to 55° (Plate XIII p 56). It shows several
subsidiary breaks, some healed with calcite, others showing slickensided skarn. On the north rim of the pit, skarny rocks are thrust on top of less altered volcanics. Footwall rocks, where relict bedding is preserved, are folded upwards. Where this fault occurs underground it lies along the footwall of the easterly dipping West Pipe dyke. Limestone is folded sharply in what is interpreted as an overturned fold, against the greenstone dyke. Whether this fold has been formed as a result of reverse movement on the fault, is not clear. The upper contact of the dyke does not appear to be a fault contact. Selvages of magnetite and skarn occur along the fault where it is exposed underground (Plate V p 48). Aside from the main thrust at least three other faults of this attitude are recognized but do not show the same reverse movement. These cut the Merry Widow zone below and subparallel to the main thrust, less prominent than the latter.

Time Relation Between Geologic Events

The suggestion has been made earlier in this report that greenstone dykes, sills and masses, in part, have been emplaced during folding of limestone. It has further been suggested that folding at Empire mine is related to the Coast Copper intrusion. Hoadley (1953 p 37) has suggested that the pronounced lineation of the Coast intrusions of Northern Vancouver Island -

"- - - - more or less parallel with the general fold structure of the invaded rocks indicates that the intrusions were associated with orogenic disturbances and that they were intruded at about the time the invaded rocks were folded."

Evidently the final stages of Bonanza volcanism, regional folding,
intrusion of Coast Copper stock with associated local folding and mineralization, were more or less contemporaneous. The close time relation between intrusion and orogeny may in fact have been a significant factor in the formation of ore deposits associated with Coast Copper stock.
CHAPTER IV SUMMARY AND CONCLUSIONS

The Merry Widow, Kingfisher and Raven ore deposits occur at the contact between Quatsino limestone and overlying Bonanza volcanic rocks near the margins of the Coast Copper stock. The stock is a composite intrusion consisting of a two-phase early system of diorite with gabbroic border phases later cut by a more acidic monzonite intrusion. Deposition of magnetite has occurred within an embayment in the stock where country rocks have been more intensely deformed. Both limestone and volcanic have been locally deformed, the limestone folding in response to stresses; the volcanic rock fracturing.

The Merry Widow deposit occurs as easterly plunging tabular ore-bodies within a wedge of meta-volcanics that have been folded into a north-westerly-trending anticline. Shape of the orebodies to some extent, reflects the configuration of the fold but also corresponds closely to easterly-dipping intrusive contact along which it lies. Superimposed on the westerly limb of this fold is an overturned fold possibly a drag-fold in limestone trending east of north and dipping easterly. The overturned limb abuts against the upper contact of an easterly-dipping andesite dyke. Along the lower contact of the dyke, is a thrust fault with strike and dip almost parallel that of the axial plane of the fold. Relations suggest that during emplacement of the Coast Copper stock, both volcanic rocks and limestone responded to the stresses produced by forceful intrusion, first by folding, then as stresses increased by fracturing of volcanic rocks. Limestone responded by folding, controlled somewhat by the West Pipe dyke, forming the overturned fold. A break occurred along the base of the dyke and a small reverse movement caused dragfolding on footwall volcanic rocks.
Away from the contact folding is less intense. In the Kingfisher zone, deformation has been mild.

The Kingfisher, Merry Widow and Raven deposits, all lie along northeasterly faults. The Kingfisher fault cuts through both Merry Widow and Kingfisher deposit. I believe this fault has provided the necessary channel for mineralizing solutions. Where it intersects fractured volcanics of the Merry Widow, upper contact of the West Pipe dyke, and crisscrossing greenstone dykes of the Kingfisher, there has been a concentration of magnetite. Structural controls then at Empire mine are:

1) Configuration of the intrusive contact. Of thirteen magnetite deposits along or near the margin of the stock productive deposits and those near economic size lie in re-entrants in the stock.

2) Deformation of the country rocks. Fracturing of volcanic rocks during folding provided easy access for mineralizing solutions.

3) Northeast faulting, in particular the Kingfisher fault, provided the main channel-ways for mineralizing solutions.

4) Presence of greenstone dykes and sills in the Kingfisher deposit where these intersect the Kingfisher fault, provide favourable sites for deposition of ore.

Greenstone dykes and faults, where observed underground and in deep drilling, have selvages of magnetite and/or skarn along them. Magnetite occurs along the base of the limestone below the Merry Widow and following the intrusive contact. Mineralizing solutions were, for the most
part ascending and where these solutions reached favourable sites deposition occurred.
Plate I

Spherulitic lava from "Little Merry Widow" mountain showing nodular weathered surface and crude banding.
Plate II

Bedding in Bonanza volcanic rocks on the north rim of Merry Widow pit. Light veinlets cutting bedding is metasomatic "vein" rock.
Plate III

Banded magnetite in Kingfisher pit. Banding conforms to limestone bedding.
Plate IV

Western limb of an overturned fold near the volcanic-limestone contact. Entrance to the Merry Widow pit.
Plate V

Folded limestone against skarny West Pipe andesite dyke. Hangingwall of the dyke marks the surface of the main thrust fault. Dark stringers penetrating the limestone are magnetite. Andesite sill partly replaced by skarn, follows over crest of a fold unbroken. Note also irregularity of minor folds in bedding surfaces.
Plate VI

Small folds in thin siliceous bed in limestone. Siliceous beds have been broken during folding and show small displacement.
Plate VII

Boudinage structures; greenstone sill in bedded limestone.
Plate VIII

Greenstone dykes. Dyke on left has irregular contact with protrusions into limestone. Dyke on right has sharp contacts and cuts sill-like skarny projections from dyke on left.
Plate IX

Greenstone dyke in folded limestone. Fold can be traced through dyke.
Plate X

Broken pre-fold dyke showing small displacement of fragments. Larger dyke at right is undisturbed.
Plate XI

Andesite sill unbroken over crest of fold cut by later andesite dyke. Small displacement on limestone.
Plate XII

Felsite dyke in breccia zone displaced by movement in breccia.
Plate XIII

North wall of the Merry Widow pit. Bedding in volcanic rocks can be seen on upper left hand side. Main thrust dips at 50° easterly. Magnetite (mg) terminates against a steep northerly fault, post-ore basic dykes (dk) cut magnetite.
Plate XV

Kingfisher fault north wall of Merry Widow pit. Fault flattens near bottom of picture.
Plate XVI

Rusty fault surface lined with calcite. Relict bedding is visible dipping to right.
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