# THE GEOLOGY & ORE DEPOSITS OF THE SUMMIT CAMP, BOUNDARY DISTRICT, BRITISH COLUMBIA

by

HENRY THOMAS CARSWELL



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HENRY THOMAS CARSWELL

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We accept this thesis as conforming to the
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..........R. M. Thompson..........

..........[signature]..........

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## ABSTRACT

The Summit Camp, now abandoned, is located seven miles north of the town of Greenwood in south-central British Columbia. Mineral deposits in skarn zones of the camp were mined for their copper, gold, and silver values. The oldest rocks in the Summit Camp are the contorted grey cherts of the Knob Hill Formation of Paleozoic (?) age. The Knob Hill Formation is overlain nonconformably by the Paleozoic Attwood Series, made up of the shales of the basal Rawhide Formation; the limestones, chert breccia, and limestone breccia of the Brooklyn Formation; and the pyroclastics, lavas, and greenstones of the Eholt Formation. The chert and limestone breccias of the Brooklyn Formation, interpreted by some earlier workers as the results of silicification and tectonic brecciation respectively, are considered to be of clastic sedimentary origin. There is a pronounced nonconformity between the Brooklyn and Eholt Formations. These sedimentary rocks were intruded in Mesozoic (?) time by the Emma Intrusive consisting of quartz diorite, diorite and minor gabbro. This event was followed by the emplacement of the Lion Creek Intrusive, which consists of quartz diorite and syenite. In Oligocene time the arkoses of the Kettle River Formation were deposited in fresh-water basins in the area. Earlier rocks were intruded by Miocene (?) phonolite and pulaskite, that also gave rise

to flows of similar composition. Miocene (?) basic dikes are the latest rocks of the area.

Mineral deposits of the camp contain magnetite, pyrite, pyrrhotite, chalcopyrite and tetrahedrite in a gangue of skarn minerals. Skarn has formed from Brooklyn limestone as a result of the addition of heat and large amounts of Si, Al, and $Fe^{+++}$ from the Lion Creek Intrusive. The intrusive assimilated large amounts of Ca and $CO_2$ in the process. Skarn zones are controlled by proximity to the Lion Creek stock, or by a contact of limestone with other rocks, or by the presence of channelways such as faults or permeable beds. Metallic minerals were introduced into the skarn zones along fractures and foliation planes with falling temperature.

Epithermal precious metal veins that occur close to the Mesozoic (?) intrusives of the Boundary District are not found in limestone. It is believed that these veins were emplaced during a late stage in the cooling of the plutonic rocks. The earlier, higher temperature release of metals into the skarn deposits may be the result of the assimilation of $CO_2$ that locally prevented the solidification of the shell of the consolidated intrusive body. The mineralizing fluids responsible for the epithermal veins were trapped within the shell and released at a late stage by fracturing due to cooling.

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## ACKNOWLEDGEMENTS

The writer wishes to acknowledge the financial help and the opportunity to do the field work for this thesis given by Noranda Exploration Company. The assistance and advice of employees of the Company, particularly Dr. A.M. Bell, M.M. Menzies, A.D.K. Burton, H. Veerman, and K. Olien is appreciated.

The writer would also like to express thanks to his supervisor, Dr. W.H. White, and other Faculty members of the University of British Columbia for advice during the preparation of the thesis.

# I. INTRODUCTION

This thesis results from field work done in the summer of 1956 for Noranda Exploration Company, and compilation and laboratory work during the winter of 1956-57.

A. SUMMIT CAMP

The Summit Camp is between Eholt Creek and the North Fork of Kettle River about seven miles north-west of Grand Forks, the main town in the Boundary District of south-central British Columbia. The mineral deposits of this District are low-grade copper showings in skarn and silver - gold - lead veins. The deposits are associated with granodioritic intrusives. The total recorded production of the Summit Camp is 11,672 oz. Au, 326,988 oz. Ag, and 17,980,390 lb. Cu.

The mines and showings that the writer examined are the Emma, Oro Denoro, Jumbo, Mountain Rose, B.C., Rathmullen, Shickshock, Sailor Boy, R. Bell, and Bluebell properties. The Lancashire Lass, which might be included among the mines of the Camp, was not visited.

The Summit Camp is subsidiary to the better-known Phoenix Camp about three miles to the south-west, now being reopened by Granby Consolidated Mining, Smelting, and Power Company. The Phoenix deposits are similar to those of the Summit Camp, and have produced 22,000,000

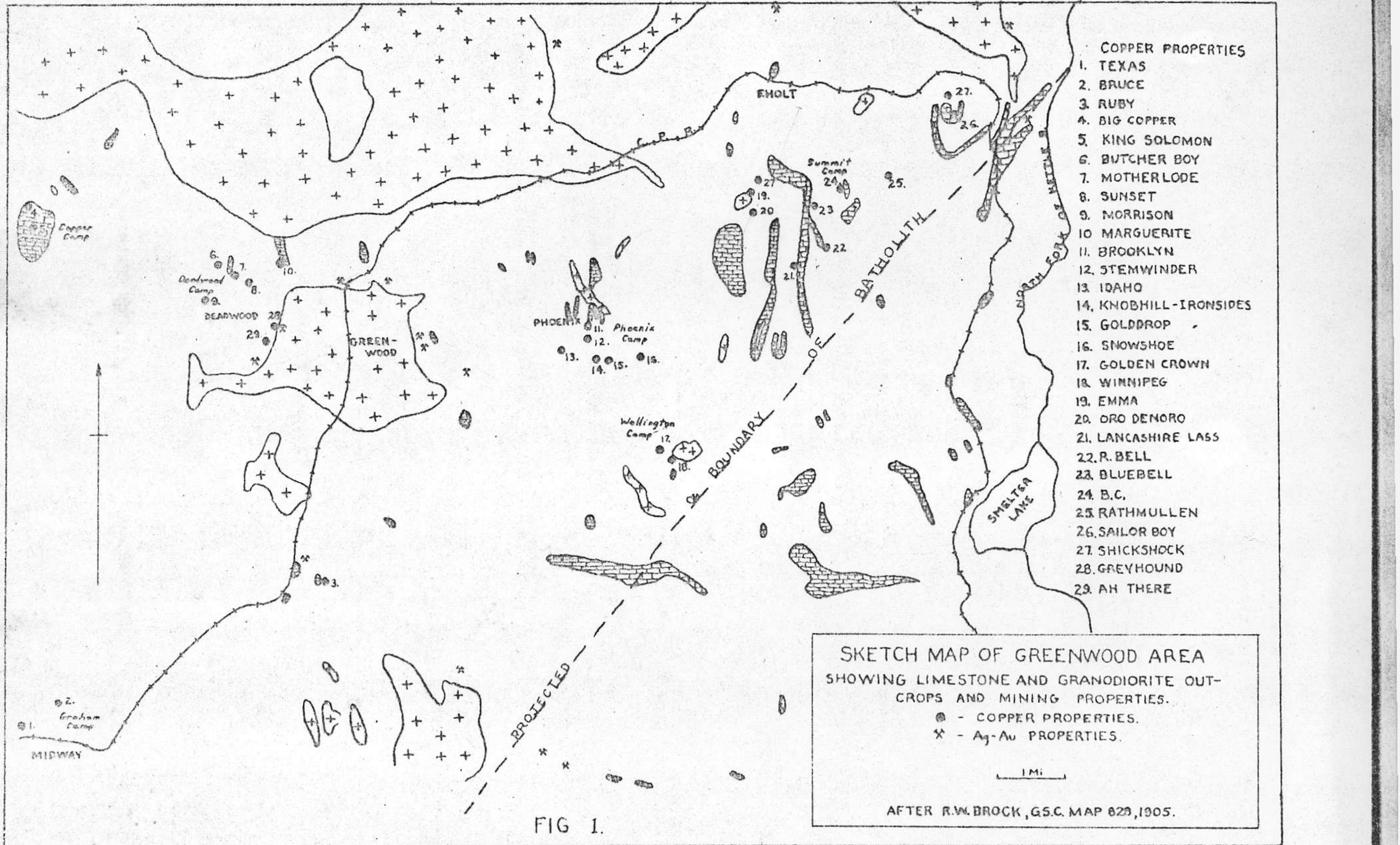
COPPER PROPERTIES
1. TEXAS
2. BRUCE
3. RUBY
4. BIG COPPER
5. KING SOLOMON
6. BUTCHER BOY
7. MOTHERLODE
8. SUNSET
9. MORRISON
10 MARGUERITE
11. BROOKLYN
12. STEMWINDER
13. IDAHO
14. KNOBHILL-IRONSIDES
15. GOLDDROP
16. SNOWSHOE
17. GOLDEN CROWN
18. WINNIPEG
19. EMMA
20. ORO DENORO
21. LANCASHIRE LASS
22. R. BELL
23. BLUEBELL
24. B.C.
25. RATHMULLEN
26. SAILOR BOY
27. SHICKSHOCK
28. GREYHOUND
29. AH THERE
SKETCH MAP OF GREENWOOD AREA
SHOWING LIMESTONE AND GRANODIORITE OUT-CROPS AND MINING PROPERTIES.
- COPPER PROPERTIES.
- Ag-Au PROPERTIES.
1 Mi
AFTER R.W. BROCK, G.S.C. MAP 828, 1905.
EHOLT
C.P.R.
Summit Camp
Copper Camp
Deadwood Camp
DEADWOOD
GREEN-WOOD
PHOENIX
Phoenix Camp
Wellington Camp
PROJECTED BOUNDARY OF BATHOLITH
NORTH FORK OF KETTLE R.
SMELTER LAKE
Graham Camp
MIDWAY

FIG 1.

tons of ore averaging 1.5% copper (Seraphim,1956).

B. HISTORY OF THE AREA

The earliest mining activity in the Boundary District was placer mining. In 1891, the Motherlode, Phoenix, and Summit Camps were discovered, and shortly afterward smelters were built at Greenwood and Grand Forks.

Summit City, located on the highway near the Oro Denoro Mine, was established in the late 1890's and became the centre of the mining population of the Summit Camp. Judging from the ruins of the abandoned settlement, it had a population of about fifty persons. About 1904 the Columbia and Northwestern Railway and the Phoenix-Eholt and Phoenix-Greenwood railway spurs were completed. Construction lent impetus to mining, which seems to have reached a peak about 1910, then slackened until 1922, when it ceased except for sporadic leasing. The Greenwood smelter shut down in 1918. Attwood Copper Mines Ltd. conducted exploration work throughout the Boundary District in 1951-53. Late in 1955 Noranda Exploration Company optioned fifty claims in the Summit Camp and began exploration.

C. DESCRIPTION OF THE AREA

The topography of the map-area is subdued and not rugged, with elevations ranging from 1,300 to 4,000 feet above sea-level. The country is in summer generally dry and hot, the runoff being discharged by minor creeks. West of the divide running through Eholt and Emma Mine these creeks are tributaries of Boundary Creek, and east of the divide they feed the North Fork of Kettle River.

Timber and brush are thick in the creek valleys, in the wet drift-covered depressions, and to a lesser extent on north slopes, while drier southerly-facing slopes are sparsely covered with grass and scattered trees.

Bedrock is mantled with a maximum thickness of ten feet of drift on the slopes, but in depressions drift may be as much as 100 feet thick (White, 1954). The glacial origin of the drift is attested to by the heterogeneity of the rock fragments in it, and by numerous erratics. A drumlinoid traps the small pond near Loon Lake. In the drift-covered bottoms outcrop is extremely scarce, but on slopes free of thick woods rock exposures are more plentiful.

Access to the map-area is provided by paved highway. Within the area the old railway grades, wagon roads, and logging roads allow easy transport by truck or jeep to most points. A foot-trail was cut to the Lime Creek area in 1956.

D. EXPLORATION PROGRAM

During the summer of 1956 Noranda Exploration Company carried on an intensive search for copper deposits in the map-area. The operation was based at the nearby town of Greenwood. Geological, self-potential, magnetometer, and soil-sampling surveys were carried out on cut lines spaced at 400 feet. In the late summer a drilling program was started, the targets being geophysical and geochemical anomalies.

E. GEOLOGICAL MAPPING

Two hundred scale geological mapping was carried on by traversing picket-lines. Although the lines were surveyed only by chain and compass, accuracy seems sufficient for the 1,000 scale compilation. Roughly, the area mapped at 200 scale is bounded by a circle of 4,000 foot radius with its centre at the Bluebell Mine. The remainder of the geology shown on the 1,000 scale sheet is 1,000 scale reconnaissance work.

In addition to this mapping program, the old surface workings were mapped by plane-table on separate sheets, which were tied in by a plane-table traverse. The caved portal of the Oro Denoro adit was opened late in 1956, and the accessible workings mapped by M.M. Menzies of Noranda Exploration Company.

Surface mapping of the area was moderately difficult because of the scarcity of outcrop and the prevalence of low-grade metamorphism. On the other hand, rocks are little weathered, and road and railway cuts offer good exposures.

F. LABORATORY WORK

Laboratory work at The University of British Columbia during the winter of 1956-57 was based on a collection of 170 specimens. Fifty-five thin sections, four polished thin sections, and thirteen polished sections were examined.

G. PREVIOUS WORK

The earliest geological work in the Boundary District was done by R.W. Brock, who mapped the entire District on a scale of one mile to the inch in 1901 (Brock, 1902). R.A. Daly mapped a five-mile wide strip along the International Boundary on a one-mile scale in 1906 (Daly, 1912). In 1912, Le Roy mapped the Phoenix Camp at 400 feet to the inch. In 1937, Mcnaughton mapped the Greenwood-Phoenix area at 800 feet to the inch and published his findings in a paper (1945) in which he agreed with the geological interpretations of Le Roy.

In 1951, Attwood Copper Mines Ltd. began exploration of the Phoenix, Summit, and Deadwood Camps. White and Allen (1954) published a paper on geological methods used in this exploration program, which proved very useful to the writer while conducting a soil-sampling program for Noranda. Geological work done for Attwood was summarized by Seraphim in a paper published in 1956.

# II. GENERAL GEOLOGY

## A. INTRODUCTORY STATEMENT

The rocks of the map-area range in age from Paleozoic to Tertiary. The oldest rocks in the area are known as the Knob Hill Formation. It outcrops at only one place in the map-area. The rock, exposed at the formation's upper contact, is a contorted grey chert. The contact between the overlying Attwood Series is probably nonconformable. The Attwood Series, of Late Paleozoic age (?), is represented in the map area by the Brooklyn and Eholt Formations. The Brooklyn Formation consists of limestone, chert breccia, and limestone breccia. This formation is overlain nonconformably by the Eholt Formation made up of pyroclastics, water-lain pyroclastics, basaltic lavas, and the chloritized equivalents of these rocks. Outside the map-area, the Attwood Series contains the basal Rawhide Formation, which consists of several hundred feet of shale.

Paleozoic rocks were intruded in Mesozoic (?) time by the Emma and Lion Creek Intrusives. The Intrusives are overlain by the Oligocene Kettle River Formation, which is composed of arkose. The Kettle River Formation does not outcrop in the Summit Camp. Country rocks are intruded by Miocene (?) pulaskite sheets and stocks and phonolite dikes. The pulaskite intrusives gave rise to flows of the same rock. All earlier rocks are cut by late dikes of varying but usually basaltic character.

B. TABLE OF FORMATIONS

| | | |
|---|---|---|
| CENOZOIC | Miocene (?) | Basic dikes<br>Pulaskite flows, dikes, and sheets; phonolite dikes |
| | Oligocene | Kettle River Formation - arkose |
| MESOZOIC (?) | | Lion Creek Intrusive<br>Emma Intrusive |
| PALEOZOIC | | Attwood Series:<br>Eholt Formation - greenstone, basalt, andesite, tuff, agglomerate, volcanic breccia<br>Brooklyn Formation - limestone, chert breccia, limestone breccia, and minor andesite flows<br>Rawhide Formation - shale<br>Knob Hill Formation - chert |

C. DESCRIPTION OF FORMATIONS

1. Knob Hill Formation*

The Knob Hill Formation outcrops in the map-area at only one place -- about 1,000 feet east of the Shickshock showing, north of Lime Creek. The rock is a strongly contorted grey chert. The strata, up to two inches in width, have in their less contorted parts a general north-west dip.

* Detailed descriptions of thin and polished sections are incorporated in the appendix.

The contact of the Knob Hill with younger rocks is obscured to the north by talus and drift, but it appears to contact the overlying Eholt Formation with little if any intervening thickness of Brooklyn rocks. To the south the Knob Hill rocks contact Brooklyn limestone that strikes north and dips vertically. The actual line of contact is obscured by drift. The Knob Hill chert had here a 55-degree south-west dip at the time of deposition of limestone: these formations, then, are nonconformable. It would appear that the outcrop of Knob Hill chert represents a hill in the old pre-Brooklyn erosion surface where lower horizons of Brooklyn sediments were not deposited.

The small-scale crumpling of the Knob Hill Formation does not persist into younger rocks. This suggests that considerable folding must have occurred in the hiatus between deposition of the Knob Hill and Brooklyn Formations.

In the Phoenix Camp, the Knob Hill Formation consists largely of cherty andesites, interpreted by Seraphim (1956), p. 685) as of pyroclastic origin, and massive andesites. Seraphim suggests that the environment of deposition of these rocks was marine. The age of the Knob Hill Formation is unknown, but thought to be Paleozoic.

2. Attwood Series

(a) Rawhide Formation

The Rawhide Formation does not outcrop in the map-area. In the Phoenix Camp it occurs as a sequence of shales several hundred feet thick that is overlain conformably by the Brooklyn Formation.

(b) Brooklyn Formation

The Brooklyn Formation consists of limestone, chert breccia, and limestone breccia.

Limestone:

Brooklyn limestone outcrops over large areas in the Summit Camp. The rock is in general recrystallized and consists mainly of calcite, with minor chlorite and quartz. The following analyses are given by Le Roy (1912) for Phoenix.

Table 1

| | Brooklyn Mine | Knobhill-Ironsides Mine |
|---|---|---|
| $CaCO_3$ | 90.41% | 98.40% |
| $FeCO_3$ | 0.16% | 0.31% |
| $MgCO_3$ | trace | trace |
| Insoluble, mainly silica | 10.00% | 1.50% |

The colour of the rock is generally white, but may be brownish or grey. The limestone in the vicinity of the B. Bell Mine contains thin beds of massive chert as well as lenses of chert breccia and nearby exposures contain shaly partings. The limestone is strongly contorted in this area as a result of emplacement of a volcanic neck.

In places where recrystallization has not occurred, poorly preserved crinoid stems and brachiopods are found that roughly date the Brooklyn Formation as Paleozoic or Triassic.

Because recrystallization has obliterated most of the primary structures, attitudes may not be often recorded, and tops are not certain.

On the hill north of the B.Bell Mine a porphyritic andesite flow with a minimum thickness of 40 feet occurs in limestone.

Chert Breccia:

The rock here termed chert breccia is described by Seraphim (1956) and Le Roy (1912) as lying at the base of the Brooklyn Formation in the Phoenix Camp, with minor lenses at higher stratigraphic levels. However, in the Summit Camp chert breccia appears to occur as lenses distributed at various horizons within the limestone. The presence of a major basal horizon is possible, however, because the base of the Brooklyn is exposed at only one place, and here at a topographic high in the surface of deposition.

In the Summit Camp the chert breccia is similar to that of the Phoenix Camp. Its largest outcrop is in the area around Lime Creek, but minor lenses occur in limestone to the south-west along the strike of the bedding.

Chert breccia from a cut on the old railway grade north of the Phoenix Road bears a strong lithological similarity to some of the breccias of the Phoenix Camp. In this rock the fragments of chert range in shape from angular and faceted to spherical and exhibit varying degrees of roundness (Plate I, c). Surfaces of the pebbles are polished or finely pitted. The pebbles range in diameter from five millimeters to three centimeters and in colour from white through pink, red, and smoky to black. In a nearby outcrop, jasper pebbles predominate. Fragments abut in many places with no sign of coalescence. Banding in pebbles is haphazard in orientation and angular fragments of limestone are fairly common. The pebbles occur in a carbonate matrix that comprises only about five percent of the volume.

At the gradational contact of this rock with limestone, the calcite matrix comprises more of the rock, chert pebbles are smaller and more rounded, and quartz veinlets occur.

A specimen from a lens of chert conglomerate 1,500 feet east of the B.C. Mine consists of quartzite fragments up to 1.5 centimeters in diameter embedded in a recrystallized carbonate matrix with minor chlorite (Plates I, d; III, c). The matrix comprises 50 percent of the rock. The pebbles are rounded and faceted or roughly spherical. All pebbles show strongly pitted surfaces that in thin section appear as crenulations of their borders. The quartzite is inequigranular and some pebbles contain a lesser order of fragments. The pebbles exhibit bedding, which is not parallel in the various fragments. The long axes of flat pebbles are foliated in the plane of bedding of nearby limestone. Veinlets and patches of secondary calcite occur in the quartzite pebbles and single grains of quartz occur in the calcite matrix. Calcite is recrystallized and somewhat strained.

The strongly pitted surfaces of the pebbles are probably due to an overgrowth of silica not evident in specimens from other outcrops. The quartz grains on the surfaces of pebbles enlarged by secondary growth exhibit crystal faces toward the calcite matrix.

Coalescence of adjacent quartzite pebbles was observed in the siliceous residue left after solution of the matrix in HCl. The quartz grains which grew to form the bridge between the closely packed pebbles exhibit crystal faces. This minor deposition of remobilized or secondary silica may account for the coalescence of "jasperoid" fragments noted by Le Roy (1912).

In an exposure on the highway a bed of tuffaceous shale intercalated in chert breccia was observed. Chert breccia deposited after the shale had been laid down contains fragments of the shale, and the shale bed shows signs of a minor period of erosion.

Chert breccia occurring in the Lime Creek area is much coarser (fragments up to ten centimeters in diameter) and more markedly angular than the types described above. However, it exhibits a similar degree of heterogeneity of colour of fragments.

Because the chert breccia has been interpreted as the result of silicification, fracture control of silica content of these rocks was looked for in the field. No major control of silica content by faults, breccia zones or joints was observed. The chert breccia near Lime Creek, though near a fault, shows no evidence of silicification. A few minor quartz veinlets accompany silica overgrowth and occur in limestone and skarn associated with mineral deposits, but such silica occurs only as comb quartz or chalcedony.

The chert breccia of the Phoenix Camp has been interpreted by Brock (1902), Le Roy (1912), and McNaughton (1945) as jasperoid. This was defined by Spurr (1898) as "... a rock consisting essentially of cryptocrystalline, chalcedonic or phenocrystalline silica which has formed by the replacement of other material, ordinarily calcite or dolomite." Spurr notes that the macroscopic character of jasperoid simulates that of a chert breccia or chert conglomerate with a calcite matrix. In the Aspen District described by Spurr silicification is controlled by faults and breccia zones that allowed access to the silica-bearing solutions. Jasperoidal nuclei coalesce to form solid chert layers parallel to the zones of shearing. The ore deposits of the Aspen District are invariably accompanied by jasperoid.

In the Phoenix Camp, Le Roy observed what he interpreted as coalescence of jasperoidal nuclei, residual fragments of limestone in jasperoid, concentration of silicification along joints, and the invasion of intrusive and volcanic rocks by similar silicification. He attributed silicification to solutions ascending along fractures and states that the siliceous rocks of the Knob Hill Formation are probably the result of complete silicification of porous tuffs by the same solutions.

McNaughton (1945), in addition to Le Roy's data, noted open spaces supposedly due to contraction during replacement, and a few fragments of igneous rocks in jasperoid. He agrees with Le Roy that the rock here termed chert breccia is the result of silicification.

On the other hand, Seraphim (1956) maintains that these rocks are of sedimentary origin, and refers to them as "sharpstone conglomerate". Some of the reasons for Seraphim's theory are:

(i) The chert fragments are banded, and in adjacent fragments orientation of banding is haphazard.

(ii) The composition of the fragments varies over short distances, the rocks being slate, jasper, chert, and rarely, igneous rocks.

(iii) "Several outcrops containing interbedded fragmental rock and siltstone or shaley siltstone show good scour and fill structure".

(iv) Limestone 'remnants' may be of sedimentary origin.

(v) Fragments that appear to be windworn pebbles occur in the sharpstone conglomerate.

(vi) Coalescence was not observed by Seraphim.

Dr. W.H. White pointed out to the writer an outcrop in Phoenix where chert breccia exhibits a gradational contact with limestone breccia. Both rocks here appear to be of sedimentary origin.

To the observations made by Seraphim in the Phoenix Camp that favour a sedimentary origin for chert breccia, the writer can add the following observations from the Summit Camp:

(i) Chert pebbles occur in contact with each other without coalescence (in the absence of silica overgrowth).

(ii) No evidence of silicified zones along fractures was observed.

(iii) Orientation of flattened pebbles in chert breccia conforms to the bedding of limestone.

(iv) Some pebbles have indisputable sedimentary shapes.

Most of Seraphim's observations were corroborated in the Summit Camp.

Limestone Breccia:

Limestone breccia occurs as lenses in massive limestone. The lenses commonly grade into chert breccia. The limestone fragments are angular to rounded, range in diameter from one to ten centimeters, and consist of calcite of varying grain-size with minor chlorite and biotite (Plate I; a, b). Angular fragments predominate, but rounded forms are common. In one exposure, limestone fragments exhibit "pillow structure", as if they had been deposited clastically while still soft. This structure is believed to be the result of fracturing and recrystallization of calcite along the fractures.

Breccias consisting predominantly of limestone fragments are commonly pyritized. At the B. C. Mine, well-mineralized limestone is in part of brecciated character. It is possible that the clastic nature of the rock made it susceptible to replacement by ore-bearing solutions.

Le Roy (1912) attributed the limestone breccia of the Phoenix Camp to faulting. No relation of limestone breccia to known faults was observed in the Summit Camp. Seraphim (1956) designated two 100-foot thick lenses of this rock found in the Phoenix Camp as Stemwinder Limestone and interpreted it with reservations as a sedimentary breccia. He noted that some fragments appear to be broken apart in places but based his conclusions mainly on the association of limestone breccia with chert breccia, which he believes to be undoubtedly of sedimentary origin.

The writer observed complete gradation of limestone breccia to chert breccia in the Summit Camp. It is therefore believed that the limestone breccia is of sedimentary origin.

Origin of the Brooklyn Formation:

The association of massive limestone with clastic limestone fragments or chert fragments is not uncommon. Seraphim (1956) visualizes the massive limestone as having been deposited in quieter, deeper water than the clastic phases:

> Rapid erosion and deposition later formed the Upper Brooklyn conglomerates and greywacke. The upper limestone 'breccia' bands may have formed from erosion of the Lower Brooklyn limestone or of the larger bands of Knob Hill limestone than now exposed.

It is considered probable that the massive limestone was deposited under quiet shallow marine conditions whereas the lenses of breccia were the result of sudden short influxes of siliceous terrigenous debris. Associated strong local marine currents eroded the calcareous sediments of the sea floor, and deposited their loads as a gravel or rubble of unsorted chert, quartzite, limestone, shale, and igneous rock fragments. The chert and quartzite pebbles are probably derived from the siliceous rocks of the Knob Hill Formation.

Although chert conglomerate is in places associated with chert layers in limestone, these do not appear to have been the main source of the chert pebbles. The fragments show signs of long transport and there is no evidence of a period of erosion after chert deposition. It seems unlikely, therefore, that the chert fragments were derived from the primary beds. Although erosion of all the clastic particles in a marine environment is not precluded, the presence of rounded pebbles of very hard rocks and wind-worn pebbles indicates a terrestrial origin for some of the chert fragments.

Structure of the Brooklyn Formation:

The scarcity of reliable attitudes in the Brooklyn Formation makes interpretation of structure difficult. At best it might be said that the prevalence of bedding that strikes north-east and dips steeply north-west or vertically indicates a general homoclinal structure or a series of isoclinal folds with their axial planes dipping vertically. Because Seraphim (unpublished map) found to the south of the map-area north-plunging folds that can be projected into the Summit Camp, it is probable that the latter idea is more nearly correct.

Strong contortion of limestone occurs in the vicinity of the volcanic neck at the B. Bell Mine. Here, folded chert beds have minor faults with offsets of a few inches whereas the less competent limestone is unfractured. A few small drag folds were noted elsewhere in limestone.

Because of the obscurity of the structure and lack of outcrop of the base of the Brooklyn Formation, no estimate of its thickness is attempted. Seraphim (1956) suggests a thickness of 3,700 feet.

(c) Eholt Formation

The name 'Eholt Formation' is hereby proposed for a sequence of volcanics formerly included in the Brooklyn Formation (Seraphim, 1956). The reasons for the separation of the two units are the presence of pronounced nonconformity between the two and the marked difference in lithology. The name 'Eholt' is taken from a railway station in the map-area. The term, of course, has purely local significance.

Brock (1902, p.97) describes the Eholt rocks of the entire area as follows:

> This series of rocks consists of green tuffs and volcanic conglomerates and breccias, fine ash and mud beds, flows of green porphyrite and probably some interbedded limestones and argillites. The tuffs, conglomerates and breccias consist of a mixture of pebbles and boulders of porphyrite material with a great many fragments (probably a large proportion) of the rocks through which the volcanics burst. Pebbles and boulders of limestone, argillite, jasper, and chert are common. Such of serpentine and old granite and old conglomerate are much rarer. In form the pebbles and boulders are rounded, subangular, angular, and of irregular and fantastic outline... Sometimes the matrix seems to be formed of porphyrite injected between the boulders....Owing to the alteration of these rocks,... it is not possible to separate the porphyrites from the pyroclastics, on the map.

In the Summit Camp the Eholt Formation consists of tuffs, agglomerates, water-lain pyroclastics, volcanic breccias, andesitic and basaltic flows, and the chloritized equivalents of these rocks. Some of these units are shown on the map where possible, the remainder of the Eholt Formation being designated as undifferentiated. The map-unit 'undifferentiated greenstone, basalt, andesite, and pyroclastics' includes chloritized types of all facies in addition to the few recognizable lavas. These stratified rocks consist of a series of interbedded lenses.

Stratified Eholt Pyroclastics:

The tuffs and agglomerates and their metamorphosed equivalents locally comprise a large part of the Eholt Formation. The agglomerates are characterized by a high percentage of fragments of country rocks, mainly quartzite probably of Knob Hill origin, whereas few fragments of Eholt lavas occur. Other fragments are of shale, limestone, and tuff. The matrix of the agglomerates is generally composed of fine tuff, but in a few places the matrix is of andesite. The fragments range in size from one millimeter to ten centimeters.

The macroscopic appearance of most of these agglomerates is not obviously fragmental, the fragments being indistinct due to metamorphism of the rock as a whole. Where the rock has been subjected to strong stress, agglomerates composed predominantly of quartzite fragments simulate the appearance in hand specimen of a contorted impure quartzite. Such contorted rocks outcrop over small areas on the hill between B.C. Creek and the western branch of Rathmullen Creek.

The shapes of the fragments vary from angular to more common rounded and spheroidal forms suggestive of aqueous deposition. These rounded shapes are exhibited by quartzite fragments. One specimen from 200 feet west of the B.C. Mine has quartzite fragments undoubtedly deposited by water. The pebbles, spheroidal or faceted with smooth rounded surfaces, occur in a tuffaceous matrix as thin (five to fifteen centimeters) strata intercalated with bedded tuff (Plate II; c). In a thin section of the agglomerate irregular quartzite fragments which have suffered little transport by water can be seen as well as water-worn pebbles.

The matrix of the agglomerates in general is tuffaceous and fine-grained, containing larger quartz grains derived from the same source as the ~~larger~~ pebbles. Being fine-grained and for the most part altered, the matrix is not easily interpreted, but appears to be composed of minute broken and corroded crystals of plagioclase, orthoclase, and fragments of volcanic glass that in a few instances exhibit shard texture.

One agglomeratic tuff simulates macroscopically a granite having inclusions of quartzite and tuff. This rock actually contains large (up to two millimeters) broken crystals of orthoclase, plagioclase, quartz, and minor magnetite, and large agglomeratic fragments all cemented by a small amount of fine-grained tuff.

The rocks referred to as tuff and in places designated on the map all contain some amount of agglomeratic fragments and consist mainly of material similar to the matrix of the agglomerates. White tuff composed mainly of quartz grains occurs on the hill north of Emma Mine. This rock is found also as xenoliths in Emma quartz diorite. Fine-grained tuff from the locality near the B.C. Mine has a finely stratified appearance attributed to aqueous deposition. Coarse agglomeratic tuffs outcropping 1,000 feet to the south-west exhibit rough stratification into layers about one centimeter thick.

The tuffaceous phase of the stratified volcanics has been in places strongly altered to clinochlore, pennine, calcite, sericite, biotite, kaolinite, and epidote. Replacing minerals take the form of a fine-grained mat of crystals, or, in the case of calcite, of irregular patches and veinlets. Agglomeratic fragments are rarely strongly altered, but are cut by veinlets of the products of alteration. Such altered agglomerate is usually recognizable in the hand specimen. In consequence, most of the rocks mapped as greenstone are probably derived from tuff and lavas rather than from agglomerate.

Extreme alteration associated with shearing was noted in a few places, the resulting rock being a fine-grained chlorite schist.

Lavas:

Recognizable Eholt lavas are less common than pyroclastics. They are typically basaltic and less commonly andesitic. One outcrop of andesite exhibits flow banding, but the lavas are in general devoid of primary structures.

A few basalt dikes that cut chert breccia north of Lime Creek may be connected with Eholt vulcanism. Due to the similarity between Eholt basalts and basic dikes of known post-pulaskite age, some Eholt volcanic rocks may be wrongly included in the Tertiary map-unit.

Volcanic Breccia and Tuff Pipes:

Two volcanic pipes were found in the map-area. They are filled with pyroclastic material similar to that occurring in the stratified pyroclastics, and are surrounded by beds of these pyroclastics.

One of these necks is located 3,000 feet north-east of the B.C. Mine and is oval in plan with a long axis of about 2,000 feet and a short of about 1,000 feet. It is intruded by pulaskite and later dikes. The Eholt volcanic breccia is made up of mainly angular but in part rounded fragments up to fifteen centimeters in diameter. The fragments are of fine-grained pink syenite of unknown origin, chert, quartzite, shale, and tuff. The rock is slightly foliated and in general silicified. Microscopic patches of carbonate, probably primary, and hematitic veinlets occur in the tuff fragments. Although the limestone-neck contact is obscured by pulaskite intrusions and drift, the geological body is interpreted as a volcanic pipe on the basis of the angularity, coarseness, and heterogeneity of composition of the breccia fragments. In addition, the breccia contains the carbonate remnants found in another volcanic body more definitely identified as a pipe.

This second pipe occurs immediately northwest of the R. Bell Mine. It is irregular but roughly circular in plan with a diameter of about 2,000 feet, and is cut by three types of later dikes. The contact of the volcanic pipe with older rocks is exposed 600 feet of the main shaft of the R. Bell Mine. The only effect of thermal metamorphism on impure limestone at the contact is slight recrystallization. The limestone is strongly deformed, however, exhibiting contortion and tectonic brecciation.

The tuffs, breccias, and agglomerates filling this pipe have in places a foliated appearance. In general the rocks are dark green and dense, with vague rounded to angular fragments. Although the fragments are commonly chloritized and epidotized, dacite, quartzite, and limestone types can be recognized. The matrix is in part andesitic and in part tuffaceous. The tuffaceous phases of the rock are composed of small crystal fragments of orthoclase and plagioclase; rounded chert, jasper, and quartzite fragments; calcite and crystals of pyroxene. A thin section of a finer-grained tuff contains 70 percent of broken feldspar crystals strongly altered to phyllosilicates and magnetite, quartzite fragments and fragments of corroded and recrystallized arenaceous limestone in a very fine-grained tuffaceous matrix. The rock is partly altered to clinochlore and epidote. Macroscopically the same rock shows strong patches of epidotization, and calcite and hematite. The rocks of the pipe contain disseminated pyrite.

The interpretation of this rock as a volcanic neck is based on the contortion and brecciation of limestone about the body, recrystallization of limestone at the contact, the rudely circular shape of the body, and the strong alteration in the neck that sets it apart from other Eholt rocks.

The concentration of chloritization and epidotization in the rocks of the pipe is believed to be connected with the formation of skarn at the R. Bell Mine.

Because neither impure limestone in contact with the pipe nor limestone fragments within the pipe have been converted to skarn it is unlikely that the skarn zone at the R. Bell Mine is a result of Eholt vulcanism. The limestone-pipe contact may have served as a channel for metasomatizing fluids connected with the intrusion of Lion Creek rocks.

A small outcrop of coarse volcanic breccia 1,000 feet west of the Emma Mine along the Phoenix-Eholt grade may be part of a third volcanic pipe. Pyroclastic rocks are very common in the vicinity.

Origin of the Eholt Rocks:

The opening stages of Eholt vulcanism were probably marked by quiet extrusion of basic lavas interspersed with stages of explosive vulcanism.

The occurrence of the breccia pipes described above indicate that the final stage of Eholt vulcanism was explosive. The fair degree of sphericity and rounding of many of the agglomeratic fragments suggests that many of the pyroclastics are water-lain. The rounded quartzite fragments, which are common in the agglomerates, probably were derived from the same source as the pebbles of the chert breccia, and were in part deposited by water as pebbles in a matrix of water-lain volcanic ash.

Structure of the Eholt Formation:

The contact between the Brooklyn and Eholt Formations is in part intrusive as described above, but in general the contact is a nonconformable sedimentary one in the Summit Camp. The fact that the attitudes of bedding and foliation in the two formations do not match is evidence supporting this interpretation. In addition, Dr. W.H. White (personal communication) found an ancient weathered zone between the two formations on the hill north of the Phoenix Road. The contact is well-exposed at the B.C. Mine, where, although unaccompanied by ancient weathering, it is definitely uneven.

Due to strong alteration of the rocks, the nature of their folding is obscure. Despite strong contortion, the general strike of the rocks can be seen to be northerly. Because of the obscure structure of these rocks no estimate of their thickness is attempted.

Mineralization of the Eholt Formation:

Eholt rocks contain few mineral deposits. None are economic. A few "gopher holes" have been sunk on pyrite concentrations associated with shearing and contortion in the Lime Creek and Rathmullen Creek areas, but, judging from the old workings, work was soon abandoned. Extensive pyritization was indicated by self-potential work over the Lime Creek showings. Disseminated pyrite is common in Eholt greenstones.

On the hill north of Emma Mine and at the B. Bell Mine, slight skarn metasomatism of Eholt rocks is evident. The skarn is mineralized by magnetite and sulphides.

3. Plutonic Rocks

In describing the plutonic rocks of the area, Brock (1902, p.107) states: "From the way in which this rock makes its appearance in all parts of the district it is evident that the whole of it, at no mean depth, is underlain by this rock."

The age of these rocks has been suggested to be Mesozoic on the basis of correlation with similar intrusives of the south-central Province. In the Summit

Camp these rocks have been divided into two map-units of slightly different age. The age relations were established by the discovery of xenoliths of one plutonic type in the other (Plate II;b).

(a) Emma Intrusive

The name "Emma Intrusive" is proposed for a small stock and a few dikes outcropping near the Emma Mine. The stock extends below the Oro Denoro Mine. The rocks of the complex are of diverse types. The most abundant rock type is quartz diorite, but diorite and gabbro also make up part of the intrusive. Quartz gabbro occurs at only one outcrop.

The texture is in general porphyritic, the light-coloured and strongly altered plagioclase crystals forming the phenocrysts. The groundmass consists of varying amounts of quartz, plagioclase, biotite or hornblende, chlorites, and accessory magnetite. Magnetite is partly altered to hematite. Plagioclase crystals are commonly altered to a mass of fine-grained phyllosilicates that obscures the original character of the feldspar, and the mafic minerals are more or less chloritized.

The rocks of this map-unit are heterogeneous, but most have in common such features as phenocrysts of plagioclase in a medium- to fine-grained matrix and appreciable content of quartz (five to forty percent). Plagioclase is near andesine in composition. It is possible that these rocks are part of a complex that includes basic phases.

The contact of Emma Intrusive with Brooklyn and Eholt rocks is accompanied by an only slightly chilled margin. Angular tuff and slightly metasomatized limestone xenoliths are found within the Emma Intrusive.

(b) Lion Creek Intrusive

The rocks of this map-unit consist of quartz diorite and syenite for which the name "Lion Creek Intrusive" is proposed. Lion Creek is the name of the tributary of Eholt Creek that flows west from Emma Mine. Lion Creek rocks outcrop as a stock (western boundary not mapped) in the vicinity of the Oro Denoro and Emma Mines and as a body of syenite 1,500 feet west of the B.C. Mine.

The most abundant rock of this map-unit is quartz diorite with a typically coarse-grained, slightly inequigranular texture. The rock is typically leucocratic. The primary mineral composition is, in order of abundance, plagioclase averaging $An_{39}$ in composition, quartz, hornblende, biotite, orthoclase, muscovite, and accessory magnetite (Plate III;c). Quartz is commonly interstitial, and in some places replaces feldspars as irregular patches. Feldspars are in most cases strongly altered to sericite, kaolinite, and other phyllosilicates. Mafic minerals are in part chloritized.

The coarse-grained biotite syenite that outcrops near the B.C. Mine has orthoclase as the predominant feldspar, but the less abundant plagioclase has a composition ($An_{45}$) within the range of andesine. The rock contains almost ten percent of quartz. Because the plagioclases are of similar composition and both rocks are leucocratic, the quartz diorite and biotite syenite are assumed to be genetically related.

A 20-foot thick dike of very coarse-grained granite porphyry cuts limestone on the Phoenix-Eholt grade south of the Oro Denoro. Althoughthe dike was mapped as Lion Creek, its true relation to other igneous rocks is unknown. Shasket Creek Type?

The syenite and quartz diorite occurring in the open pits of the Oro Denoro Mine are strongly epidotized, hematitized and carbonatitized near the extremely vague skarn contact. This indicates that the Lion Creek Intrusive may have been responsible for the formation of skarn. A few narrow Lion Creek dikes cut skarn in the Oro Denoro pits.

The main stock has a very flatly dipping roof beneath the Oro Denoro Mine as can be seen in underground workings and deduced from drilling in the vicinity. Brock (1902, p.121) states that it occurs at no great depth below the B.C. Mine.

4. Kettle River Formation

The Kettle River Formation does not outcrop in the map-area, but occurs in the Boundary District. Its age is established as Oligocene by plant fossil dating (Le Roy, 1912, p.44). In the Phoenix Camp the formation is composed of arkose and has a thickness of a few hundred feet. Kettle River rocks throughout the south of the Province are interpreted as having been deposited in fresh-water basins. At Phoenix, the Kettle River Formation is overlain with slight disconformity by Miocene (?) flows.

5. Miocene (?) Igneous Rocks

These rocks, which are in part the "Midway Volcanic and Hypabyssal" rocks of Seraphim (1956), include in the Summit Camp pulaskite flows, sheets and stocks; phonolite dikes; and a few late basaltic dikes.

(a) Phonolite Dikes

Three narrow dikes of phonolite occur in the map-area: one intruding the volcanic neck near the R. Bell Mine, another cutting Eholt, Emma, and Lion Creek rocks 1,000 feet west of the Emma Mine, and a third outcropping near the Mountain Rose pit. In hand specimen the rock has a very fine-grained satiny texture and a brown colour. The rock contains a few cavities that appear to be the result of weathering out of phencrysts. In thin section the rock proves to be composed of a fine-grained ground-mass of orthoclase, plagioclase, biotite and aegerinaugite with larger crystals of nepheline and a few phenocrysts of pigeonite. Phonolite is similar in composition to pulaskite, described below. These rocks are therefore believed to be very closely related.

(b) Pulaskite

Pulaskite is defined as: "... an alkaline rock composed of soda-orthoclase, soda-microcline, and microperthite and antiperthite. It may contain subordinate nepheline, sodalite, or rarely, nosean." (Williams et al, 1954). Both extrusive and intrusive phases of pulaskite occur in the map-area. The intrusive phase is brown to grey in colour and is commonly porphyritic with a fine- to medium-grained matrix. The minerals are, in order of abundance, small laths and phenocrysts of perthite and cryptoperthite; albite of the same habit; nepheline as inclusions in early minerals; biotite; hornblende; riebeckite; aegerinaugite, euhedral magnetite; rare interstitial quartz; and very rare pigeonite. Feldspars are cloudy and strongly altered to phyllosilicates, and mafics are altered to pennine and clinochlore. Where the rock is chilled against country rocks it is green and porphyritic with an aphanitic matrix. Intrusive pulaskite occurs in the map-area as extensively outcropping sheets and stocks.

Pulaskite flows have a similar mineralogical composition but mafics are more abundant and occur as larger crystals, and the feldspar phenocrysts are larger (up to one centimeter)(Plate II;d). The lavas are slightly vesicular and amygdaloidal where seen east of Eholt station along the Canadian Pacific Railway. Pulaskite lavas can be definitely distinguished from the intrusive phase only by structural features.

Pulaskite lavas occur toward the north of the map-sheet. A disconformable contact between the flows and older rocks showing slight ancient weathering is visible at many places in railway cuts. The lavas in a few places exhibit flow banding which indicates that a tilting of some 35 degrees to the north-east has occurred since the outflow of the lava.

Phonolite and pulaskite have probably become undersilicated and gained the calcium of their nepheline, pigeonite, and aegerinaugite by the assimilation of limestone. Large rounded inclusions of limestone occur in one of the phonolite dikes. The high soda content of the plagioclase, which would be expected to be calcic as a result of assimilation of limestone, can be explained by Shand's (1930) hypothesis of sinking of the dense calcic plagioclase formed. Less dense soda plagioclase would rise to take its place.

(c) Basic Dikes

Included in this map-unit are fine-grained basic dike rocks of obscure relationship to the other igneous rocks of the area. At least some such rocks occur as dikes in pulaskite. The dike rocks are porphyritic andesites and basalts and commonly contain disseminated pyrite. They may be related to the Miocene basalts that occur in many parts of interior British Columbia.

D. FAULTING

Major faults are indicated at two places near Lime Creek. The possible fault on the slope to the south of the creek was inferred on topographic evidence after examination of aerial photographs. The probable fault in Lime Creek valley shows apparent offset, and shearing and pyritization are visible along the trace. Minor faults and shear zones are visible at many places in the map-area, especially in mine workings. In some cases these faults and associated joints control copper mineralization.

## III. ECONOMIC GEOLOGY

The word "skarn" is used in this thesis as a term for a contact metasomatic or pyrometasomatic rock composed mainly of lime silicates.

In the Summit Camp, skarn has formed by the metasomatism of massive limestone beds. The metasomatic effects are believed to be the result of the intrusion of Lion Creek rocks. Figure 1 shows that in the Boundary Camp economic copper deposits are associated with limestone outcrops within the projected boundary of the granitic body. Low temperature precious metal veins occur in rocks other than limestone close to the intrusives or within them. Deposits of this type have not been discovered in the Summit Camp.

A genetic relationship between the Oro Denoro-Emma-Jumbo skarn zone and the Lion Creek quartz diorite stock is indicated by field relations. Mineral deposits not within this main skarn zone and not obviously related to igneous activity are probably the result of igneous emanations that deposited ore minerals under certain structural conditions.

A. DESCRIPTION OF MINES

Table II

Recorded Production of Mines of the Summit Camp*

| Property | Year | Ore Shipped or Treated | Gold (oz.) | Silver (oz.) | Copper (lb.) |
|---|---|---|---|---|---|
| Emma | 1901-21 | 254,597 | 6,804 | 78,065 | 5,132,118 |
| Emma-Bluebell | 1927 | 24 | 1 | 12 | 1,027 |
| Bluebell | 1938-39 | 389 | 259 | 122 | 930 |
| Oro Denoro | 1903-17 | 136,447 | 3,744 | 30,652 | 3,727,194 |
| B.C. | 1900-19 | 103,476 | 1,002 | 214,275 | 9,025,707 |
| Mountain Rose | 1904-10 | 11,629 | 6 | 178 | 48,514 |
| R. Bell | 1901<br>1902 | 294<br>560 | --<br>? | 3,559<br>? | 45,927<br>? |
| Jumbo | 1905 | -- | -- | -- | -- |
| Rathmullen | 1898 | -- | -- | -- | -- |
| Sailor Boy | 1899 | -- | -- | -- | -- |
| Shickshock | 1899-1906 | -- | -- | -- | -- |

1. B.C. Mine

The B.C. Mine is in the centre of the map-area. The deposit, which yielded ore of high grade for the Boundary District, is in Brooklyn limestone and has a hangingwall of Eholt agglomerate. The average grade for ore extracted up to 1901 was 5.6 percent

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* Data from Index No. 3, B.C. Dept. Mines, 1956, Table I and B.C. Reports of Minister of Mines for 1894-1939.

Cu, 2.45 oz. Ag, and .015 oz. Au.

The workings (see 50 scale mine map) consist of a large open pit (now flooded), a shaft, and many trenches. About 450 feet south-west of the main workings is a smaller second shaft. Access to the mine is provided by a good dirt road.

The following structural description is from Brock's (1902) observations during the operation of the mine in 1901. The main ore body is 65 feet wide and 200 feet long, becoming smaller with depth. The walls of the ore body are merely commercial walls, but the "marble line" is sharp. The mineralized zone is cut by numerous sheets of pulaskite that contain no inclusions of ore. Diamond drilling to a depth of 911 feet indicated the presence of ore below the 400-foot level, but increasing amounts of pulaskite intrusive proved discouraging. Granodiorite was encountered in drilling. A few dikes similar to those of known post-pulaskite age are exposed in the main pit.

The gangue is limestone, skarn, and, according to Brock (1902), probably in part altered Eholt greenstone. Brock noted the following minerals in the gangue: garnet, quartz, calcite, dolomite, epidote, zoisite, actinolite, chlorite, serpentine, plagioclase, and kaolin (?). A specimen of ore from the main pit consists of pyrrhotite replaced by chalcopyrite that contains minute blebs and veinlets of tetrahedrite. The metallic minerals replace granular quartz gangue as massive pods and small stringers. The specimen is veined by late calcite. Spectrographic analysis indicates the presence of gold in pyrrhotite.

Ore minerals also replace fine-grained garnet-epidote skarn, limestone, and limestone breccia as massive pods and fine-grained disseminations. This mineralization appears to be related to faults, the pods of massive ore occurring in their footwalls.

2. Emma Mine

Emma Mine is one of the major mines of the Camp. It is near the contact of the main skarn zone with Emma quartz diorite at the junction of the old Phoenix-Eholt and B.C. Mine railway spurs. Access is provided by these old grades.

The workings consist of an inclined shaft, four deep open stopes, water-filled underground workings on six levels, some trenches, and a prospect shaft (see 50 scale mine map).

An old composite level plan indicates that the ore body was a north-striking lens 600 feet long by 30 feet wide. The ore body dipped steeply to the east and raked north. Mineralization grades off to the north but apparently terminates abruptly to the south.

(Unfortunately there are no surface exposures of this end of the mineralized zone.) The attitude of the ore-body conforms to the bedding of limestone.

Skarn contacts Lion Creek quartz diorite at the south end of the deposit (see 50 scale mine map). The lens of skarn lies against a steep contact of Emma quartz diorite. The skarn zone is cut by pulaskite and granodiorite dikes. Strongly metamorphosed Eholt pyroclastics outcrop on the footwall of the ore zone.

The hangingwall of the oreshoot contains a diffuse unmineralized zone of calcite two to ten feet thick that parallels the foliation. A persistent one-foot thick layer of massive magnetite occurs adjacent to the calcite zone for a distance of 250 feet. In general, magnetite is localized along foliation planes, but sulphides commonly occur as irregular pods that are most numerous toward the footwall.

In hand specimen, skarn ranges in character from fine-grained light-coloured andradite rock to porphyroblastic replacements of marble by coarse-grained dark brown andradite, epidote, and diopside. In thin section, skarn proves to contain in addition calcite, zoisite, quartz, and minor scapolite and plagioclase.

One specimen contains brecciated fragments of andradite-diopside skarn. Spaces between fragments have been filled with coarse-grained magnetite with some andradite and diopside. The boundaries of the fragments are partly replaced by magnetite. Another specimen exhibits what are interpreted as elongate brecciated fragments in an originally open fracture. Some of these fragments are bordered by radiating clinozoisite crystals, and the area between the encrusted fragments is occupied by magnetite with minor diopside. Brecciated skarn was not found in place. Although some magnetite appears to have filled fissures, most has replaced country rock.

The metallic minerals are magnetite, chalcopyrite, tetrahedrite, and a very few minute white isotropic blebs of an unidentified mineral. In most cases, magnetite replaces skarn along foliation planes and fractures. Pyrite replaces and cuts magnetite. Chalcopyrite replaces earlier metallic minerals and silicate gangue as veinlets, and calcite as irregular bunches. Tetrahedrite and the unknown mineral occur in chalcopyrite as minute blebs. Late calcite veinlets cut all earlier minerals.

It was observed in the open stopes that copper mineralization is strongest in the footwall of the orebody.

3. Swallow Mine

The term "Swallow Mine" is used by the writer to denote a pit on the Emma claim (see index map). This pit is 800 feet south-west of Emma Mine proper, and lies within the main skarn zone in line with the north-east extension of it (see 1,000 scale geological map). The Swallow pit was reportedly worked in conjunction with the Oro Denoro Mine. The workings consist of a water-filled pit with two stopes or drifts in the north face and an incline in the south face (see 50 scale mine map).

A steeply dipping lens of marble covers most of the north face of the pit. Two flat-dipping sub-parallel faults are exposed in this face. Skarn is cut by a set of joints parallel to these faults. At the norty-west corner of the pit zones of magnetite occur along a breccia zone, and a large area of magnetite is exposed in the east face. At the north-east end of the pit, pyrite and calcite replace skarn along north-east striking steeply dipping foliation planes.

The following observations regarding gangue and metallic minerals are based on examination of specimens collected from the dump. Skarn consists of andradite, clinozoisite, actinolite, quartz, calcite, and sphene. Andradite is partly altered to chlorite.

Skarn replaces very coarse-grained marble as coarse- to fine-grained aggregates. Residual calcite occurs in interstices between silicate crystals or as unreplaced zones.

Magnetite replaces calcite and, to lesser extent, silicates. Pyrite bears similar relations to gangue. Chalcopyrite, pyrrhotite, and a little tetrahedrite cut magnetite, pyrite and silicates and replace calcite extensively. Late calcite veinlets cut all other minerals.

Some specimens of ore show a striking brecciated texture and features suggesting open-space filling. Plate II;a illustrates one of these specimens. Brecciation of foliated andradite skarn is proved by the disorientation of the foliation of angular fragments in this specimen. These fragments were encrusted and slightly replaced by coarse-grained magnetite and andradite. This stage was followed by deposition of andradite alone, then by deposition of epidote and radiating crystals of actinolite. The final stage of open-space filling was the deposition of calcite in the remaining space. Replacement of earlier minerals by minor amounts of sulphides then occurred.

Paragenesis is similar to that described above for other specimens of brecciated skarn. The main points in favour of an open-space filling origin of these textures are:

(a) The established brecciated nature of the original skarn.

(b) The concentric nature of the mineral zones.

(c) The cockade texture of actinolite.

(d) The fact that a rough paragenesis holds for several specimens.

The medium that deposited the encrusting minerals may have been fluid moving through an open jumble of skarn fragments.

4. Jumbo Mine

The Jumbo Mine is a minor showing near the north end of the main skarn zone. It lies in metasomatized Brooklyn limestone near its contact with Eholt volcanics. The showing was worked in 1905, but has no recorded production. The workings consist of a shallow shaft, two open cuts, and three trenches (see 50 scale mine map). The showing can be reached from Emma Mine by a badly overgrown wagon road.

The deposit is in an apparently narrow zone of green andradite skarn that grades into slightly metasomatized limestone breccia. Foliation of skarn is parallel to the bedding of limestone. Minor shears occur at the north end of the main cut . The skarn zone appears to end to the north between the northern open cut and the trenches.

Skarn consists of fine- to medium-grained green andradite crystals with inclusions and interstitial fillings of calcite, quartz, and scapolite. The rock is cut by veinlets of calcite and quartz, the quartz veinlets being partly replaced by magnetite and minor specularite. Chalcopyrite and magnetite occur as pods replacing calcite which is interstitial to garnet crystals (Plate III;c). In a polished section of the ore, these pods are seen to be associated with a magnetite-hematite veinlet. Chalcopyrite contains a few blebs of tetrahedrite. Pyrite cubes replace garnet.

5. The "Pyrrhotite Showing"

This small prospect shaft is in Eholt greenstone on the hill north of the Emma Mine. A specimen of ore from the dump consists of euhedral pyrite crystals and massive pyrrhotite cut and replaced by chalcopyrite containing blebs of tetrahedrite. The gangue is andradite skarn. The deposit is similar to the minor showings in Eholt rocks at the B.Bell Mine (described below) and may be related to a skarn zone in underlying Brooklyn limestone.

6. Oro Denoro Mine

The Oro Denoro Mine is in the centre of the main skarn zone on the Phoenix-Eholt railway spur.

The visible workings consist of a main adit, about 1,000 feet of drifts on one level, five open stopes, and a deep prospect shaft.

The oreshoots occur in a skarn zone that appears to be floored by a body of Emma diorite. The contact of the diorite dips to the north-west at a low angle. Country rocks are cut by the Lion Creek stock, which is evident in the open stopes (see 50 scale mine map). Skarn is cut by narrow dikes of diorite, Lion Creek quartz diorite and pulaskite. The Lion Creek stock contains a roof pendant or salient of limestone converted to mineralized skarn that comprises the north half of the Oro Denoro deposit, the south half being part of the main skarn zone. Both roof pendant and main skarn zone contain disseminated metallic minerals within a few feet of the Lion Creek contact, whereas richer zones occur along fractures further within the skarn bodies. Magnetite replaces skarn along foliation planes as at Emma Mine.

In general, ore-controlling fractures are of two attitudes - roughly NE/V and NW/15W. Metallic minerals appear to be concentrated in the lower crotches of the intersections of fractures as well as along the vertical fractures. Skarn contains varying amounts of disseminated ore minerals and some calcite veins contain massive bunches of sulphides. At least one wide calcite vein containing brecciated fragments of skarn is exposed in the underground workings. In the underground workings a pulaskite dike is not displaced by faults which control mineralization.

Skarn consists mainly of andradite with minor amounts of diopoide, quartz, calcite, hematite, and chlorite. Epidote occurs in places as irregular veinlets and is associated with chalcopyrite. Skarn is medium- to fine-grained in texture and is in places foliated parallel to original bedding. Coarse-grained residual calcite and late hematitic vein calcite occur, in places with brecciated inclusions of skarn. In thin sections of vein calcite, crushed andradite may be seen in a matrix of quartz and calcite.

Metallic minerals replace silicates and calcite. Magnetite and minor specularite crystallized together. They replace gangue along fractures and foliation planes or form irregular patches in skarn and marble. Pyrite replaces magnetite and gangue, and late chalcopyrite with minute blebs of tetrahedrite replaces earlier minerals. In a few instances veinlets of magnetite cut pyrite, indicating that deposition of the two minerals was to some extent contemporaneous.

Chalcopyrite and pyrite occur most commonly as disseminated replacements of silicates or magnetite, or as pods of massive ore. Disseminated pyrite and pods of chalcopyrite are found at the borders of calcitic zones, and chalcopyrite occurs as pods in some calcite bodies.

Some float found in the vicinity indicates that a stage of filling of fissures by quartz occurred. The specimen collected has a two-inch wide unmineralized vuggy quartz vein containing brecciated inclusions of skarn. The vein is probably a post-mineralization feature related to late calcite-quartz veins mentioned above.

7. Mountain Rose Mine

The Mountain Rose Mine is 300 feet west of the highway at the north-east end of a narrow branch of the main skarn zone (see 1,000 scale map). The workings may be reached by wagon-road from the B.C. railway spur. The workings consist of a deep open stope from which ore was drawn into an adit (see 50 scale mine map).

The deposit occurs in a zone of skarn that exhibits a gradational contact with Brooklyn limestone. Skarn minerals replace limestone as scattered porphyroblasts which become smaller and more numerous toward the completely metasomatized rock. Irregular pulaskite intrusives and a phonolite dike cut skarn and limestone. A prominent pair of pre-pulaskite faults (NE/85SE) is evident in the open stope.

Gangue consists of fine-grained green garnet skarn. Metallic minerals are rare on the edges of the stope, and the stope floor and walls are inaccessible, so the following observations are based on examination of specimens of oxidized ore collected from the dump. Fine-grained magnetite crystals replace garnet. Pyrite replaces and cuts garnet and magnetite. Late pyrrhotite and chalcopyrite replace earlier metallic minerals, cut garnet, and replace residual calcite between garnet crystals. Tetrahedrite occurs in chalcopyrite as minute blebs.

Because little ore is exposed in the workings, it is probable that the Mountain Rose ore-body was completely mined out.

8. <u>R. Bell Mine</u>

The R. Bell Mine is one mile south of the B.C. Mine. The deposit lies in Brooklyn limestone against the contact of one of the Eholt volcanic necks. The workings may be reached by good dirt road from the highway. The workings consist of a main shaft, a caved adit, six prospect shafts in Eholt volcanic breccia, and many trenches.

Because there is no outcrop of skarn or of the main zone of mineralization, specimens of ore and gangue were obtained from the dumps. High-grade chalcopyrite occurs in marble and fine-grained skarn. Coarse-grained andradite and pods of fine-grained clinozoisite replace recrystallized calcite in some specimens. In thin section gangue proves to be composed of zoned, partly anisotropic andradite and calcite, quartz, pyrite, clinozoisite, diopside, specularite, and chlorite. Euhedral andradite, radiating sprays of hematite, and clinozoisite-dropside masses replace residual calcite. Pyrite and pyrrhotite replace calcite. Specularite veinlets cut garnet and pyrite and late calcite-quartz-earthy hematite veins cut earlier minerals (Plate III;a). Where skarn contacts Eholt volcanic breccia, there is local replacement of breccia by andradite, clinozoisite, pyrite, and earthy hematite.

The minor shafts and trenches of the R.Bell Mine are in Eholt rocks that are strongly epidotized and pyritized. Fractures in the rock contain secondary copper carbonates. In one trench a three-foot wide zone is replaced by andradite and calcite, and mineralized by fine-grained manganoan magnetite, pyrite, pyrrhotite, and chalcopyrite that show no mutual relations. Rock in this trench is heavily coated with manganese stain due to weathering of the manganoan magnetite.

Spectrographic analysis indicates the presence of gold in the pyrite of the deposit. Because skarn containing much pyrite was stockpiled, gold content of the ore is believed to have been appreciable but not recoverable.

9. Bluebell Mine

The Bluebell Mine is close to the B.C. Mine railway spur 2,000 feet west of the Mountain Rose Mine. The deposit is in metasomatized Brooklyn limestone near its contact with Eholt volcanics. The workings consist of two water-filled shafts.

Skarn outcrops as patchy replacements of limestone breccia by fine-grained brown andradite. A specimen of ore from the dump consists of euhedral coarse-grained pyrite replaced by magnetite.

10. Rathmullen Showings

The Rathmullen showings are 3,000 feet west of the B.C. Mine. The deposit lies in metasomatized Brooklyn limestone within 100 feet of an Eholt volcanic pipe. Access to the showings was provided by a wagon-road up Rathmullen Creek, but this route is now impassable. A recently built logging road from the B.C. Mine passes close to the mine.

Ore contained gold values ranging from $12 to $80, but there is no recorded production for the mine. Ore found on the dump consists of pyrite and chalcopyrite in fine-grained garnet-epidote skarn.

11. Sailor Boy Showing

The Sailor Boy showing is 1,000 feet northeast of the summit of the pass at the head of Lime Creek. The deposit is in metasomatized Brooklyn limestone. The workings consist of a water-filled shaft and a dump indicating that about 350 tons of rock were mined. There is no sign that any ore was shipped, but some strongly pyritized skarn was stockpiled.

There is no outcrop at the shaft, but fine-grained foliated light-brown garnet skarn is exposed 100 feet to the west. "Ore" consists of large euhedral crystals of pyrite in a gangue of skarn. Fragments of diorite found on the dump indicate that an intrusive body was encountered in mining.

12. Shickshock Showing

The Shickshock showing occurs on the summit of the hill north of the Sailor Boy Mine. Skarn or limestone do not outcrop in the immediate area, Eholt greenstone being visible on the surface and in the shaft. The Brooklyn Formation probably lies just below the surface. The workings consist of a caved prospect shaft with a small dump. Old reports indicate that the showing was explored from 1899 to 1906, but no production is recorded, nor is there evidence that ore was transported from the site. Specimens from the dump consist of massive magnetite replaced and cut by chalcopyrite and calcite in a gangue of fine-grained garnet skarn.

B. PRECIOUS METAL VALUES

Despite the fact that gold or silver minerals were not noted in polished sections, both elements occur in recoverable quantities in the ores of the Camp. The presence of tetrahedrite, which commonly contains large amounts of silver in solid solution, may account for silver values. Tetrahedrite occurs only in chalcopyrite, and copper values can be very roughly correlated with silver values throughout the Camp. Spectrographic analysis of tetrahedrite-bearing chalcopyrite from the B.C. Mine indicates the presence of silver.

Gold may occur either in solid solution or as submicroscopic blebs in sulphides.(Edwards, 1954, p.112). Spectrographic analyses indicate the presence of gold in pyrite and pyrrhotite but not in chalcopyrite. Relations of copper to gold values throughout the area also indicate that chalcopyrite contains little or no gold.

C. SUMMARY OF CHARACTER OF THE SKARN

Limestone is the only rock strongly affected by skarn metasomatism. In the two places where the "marble line" is visible strong recrystallization of calcite is evident. Replacement of calcite by andradite and diopside is porphyroblastic and coarse-grained in the outer zones, becoming finer-grained toward completely metasomatized rock. This fine-grained character may be attributed to competition for growing space among many crystals in the intensely metasomatized rock.

The mineralogy of skarn is fairly uniform throughout the Camp. The rock consists mainly of garnet of composition grossularite$_{10}$ andradite$_{90}$. The refractive indices of all garnets tested lie above 1.8215 and the specific gravities of clean fragments range from 3.732 to 3.742. The colour of andradite ranges from light green to dark brown. The darkness of colour is thought to vary with slight variations in iron content. Skarn contains lesser amounts of quartz, diopside, zoisite, clinozoisite, actinolite, chlorite, sphene, calcite, and scapolite (marialite?).

Typical skarn is medium- to fine-grained in texture and consists mainly of light-coloured andradite with interstitial calcite and quartz. Diopside, quartz, clinozoisite, zoisite, and scapolite occur as inclusions in andradite or as independent crystals. The skarn is cut by late veinlets of quartz and calcite, and is replaced by metallic minerals. Purely thermal effects have resulted only in recrystallization of calcite, even where the original limestone was arenaceous. This indicates that the temperatures of skarn formation were below the temperature above which quartz and calcite cannot coexist.

However, it is possible that metasomatism may have obliterated such contact metamorphic minerals as wollastonite.

The original bedding of limestone is preserved in skarn in many places. There is no evidence of open space deposition of skarn minerals.

In a few places, skarn minerals have replaced rocks of the Eholt Formation to a slight extent.

## D. LOCALIZATION OF SKARN METASOMATISM

The genetic relation between the Oro Denoro-Emma-Jumbo skarn zone and the Lion Creek stock is evident from field relations. Skarn zones not obviously related to Lion Creek contacts appear to be controlled by:

1. The presence of fractures or permeable beds in limestone that acted as channelways for metasomatizing fluids.
2. The presence of a contact of limestone with rocks less susceptible to metasomatism. The contact may have served as a channelway or "cap" for the metasomatizing fluids.

The example of the first type of control is the long zone or series of zones that extends along the strike of bedding of Brooklyn limestone and contains the Mountain Rose Mine. The remaining skarn zones of the area are believed to be controlled by contacts as outlined in 2, above. The rocks against which the metasomatized zones lie are in most cases Eholt rocks. At the R. Bell Mine, alteration to epidote in the Eholt volcanic pipe is believed to be related to skarn metasomatism. The Emma skarn zone occurs against a footwall of Emma quartz diorite.

The Sailor Boy deposit is not closely related to a contact of Brooklyn limestone with other rocks of pre-mineralization age. It is believed that the localization of skarn metasomatism at the Sailor Boy was effected by the presence of a cap of Eholt rocks now removed by erosion.

E. FORMATION OF SKARN AND MINERALIZATION

The theory that skarn metasomatism is the result of intrusion of Lion Creek rocks is indicated from field relations. For example, where limestone is in contact with the Emma quartz diorite, there is no skarn developed. Inclusions of marble showing only slight replacement by garnet are present in the Emma intrusive.

At the Oro Denoro Mine, Lion Creek rocks have gradational contacts with skarn, the intrusive being chloritized and epidotized. Many large limestone xenoliths or roof pendants occur in Lion Creek quartz diorite in the vicinity. These xenoliths are completely converted to skarn. Microscopic examination of a specimen of Lion Creek rocks containing small inclusions of skarn showed the following significant details:

1. Surrounding granodiorite contains plagioclase ($An_{30}$) more sodic than the average ($An_{39}$) for the stock.

2. Diopside and zoisite occur both in skarn and in granodiorite.
3. Within five millimeters of the contact the granitic rock contains very little free silica, but further from the contact contains 20 percent of quartz.
4. Accessory pyrite occurs in granodiorite. Within ten millimeters of the skarn contact, pyrite is much less abundant.
5. Garnet occurs in granodiorite.

These relations indicate that Fe and Si were removed from granodiorite by skarn, and that Ca was added to granodiorite. The assimilation of Ca by granodiorite has not resulted in formation of feldspathoids because of an abundant supply of free silica. The plagioclase of the granitic rock might be expected to have become more calcic than average due to addition of lime. The reverse is true, however. The sodic nature of the plagioclase can be explained by Shand's (1930) hypothesis that calcic plagioclase formed sinks due to its high specific gravity, its place being taken by less dense sodic plagioclase. The presence of high soda plagioclase might alternatively be explained by Daly's (1933) hypothesis that resurgent gases removed Ca -- much $CO_2$ was available for the process. A case of sodic plagioclase occurring at the contacts of skarn xenolith in andesite is mentioned by Brouwer (1928).

In summary, it is strongly indicated that skarn metasomatism in the area is the result of emanations and heat from the Lion Creek intrusion during its solidification.

Comparison of the compositions of skarn and limestone show that replacement involving the addition and removal of substantial amounts of material has occurred. The following calculation of the amounts of replacement are based on complete volume for volume replacement of one kilogram of siliceous limestone by 1.2 kilograms of skarn. Reasonable estimations of average compositions of skarn and limestone were chosen. It is emphasized that these calculations are based on assumed average rock compositions and hence have limited quantitative value.

Table III

1.2 kg. skarn - 85% (by weight) $grossularite_{10}$ $andradite_{90}$, 5% clinozoisite, 5% diopside, 5% quartz.
S.G. (calculated) = 3.25

1 kg. limestone - 90% calcite, 10% quartz.
S.G. (calculated) = 2.70

| | $Fe^{+++}$ | Al | Mg | Ca | $CO_3$ | Si | OH | O |
|---|---|---|---|---|---|---|---|---|
| Skarn | 209.0 | 24.8 | 6.7 | 267.2 | - | 224.1 | 2.4 | 462.3 |
| Ls. | - | - | - | 360.0 | 395 | 46.7 | - | 197.3 |
| Addition to Ls. | +209.0 | +24.8 | +6.7 | -92.8 | -395 | +117.4 | +2.4 | +65.0 |

The resulting figures give a very rough estimate of the gains and losses involved in metasomatism: Country rock gained large amounts of $Fe^{+++}$ and silica and lost substantial amounts of Ca and $CO_3$. Less important additions are Al, Mg, and OH. The rare occurrence of marialite (?) indicates addition of slight amounts of Cl.

Skarn metasomatism was overlapped and followed by deposition of magnetite. This process and the production of andradite involved introduction of $Fe^{+++}$ and $Fe^{++}$. Considering the large addition of Ca to the Lion Creek rocks, Swanson's (1924) hypothesis of replacement of $Fe^{++}$ by $Ca^{++}$ in mafic constituents of intrusives seems tenable (diopside occurs in granitic rocks near skarn contacts). Ferrous ions liberated in this way would be oxidized by $CO_2$ around 500 degrees centigrade according to the formula:

$$FeO + CO_2 \rightleftharpoons Fe_2O_3 + CO \quad \text{(Butler, 1923)}$$

These processes would provide the ferric iron of andradite, specularite, and magnetite.

Deposition of magnetite was closely followed and overlapped by sulphide mineralization. Butler (1923) considers this to be the normal order of deposition in skarn deposits and attributes the paragenesis to falling temperature. The sulphide assemblage is a mesothermal one. The usual order of deposition for the Summit Camp is pyrite, pyrrhotite, chalcopyrite, followed by the sulphosalt tetrahedrite.

Calcite deposition in fractures is evident throughout the sequence of skarn formation and mineralization. It is probable that the large excess of Ca and $CO_2$ in the introduced fluids tended to combine and precipitate wherever conditions were appropriate. Carbon dioxide and CO, which have high partial pressures, could provide driving force for replacing fluids in general.

Fracture control of mineralization indicates that fracturing occurred during metasomatism, and that the breaks produced may have served as channelways for mineralizing fluids.

Localization of mineralization mainly within skarn zones despite adjacent limestone being a more susceptible host rock may be explained in the following way. Mineralizing fluids reached country rocks through the same channelways as skarn forming emanations. Metals were precipitated in skarn. Solutions that reached limestone with some metals still present lost these rapidly by replacement of calcite, permitting massive and disseminated deposits at the "marble line." Such deposits were observed at the B.C. Mine.

The following is a generalized sequence of skarn metasomatism and mineralization for the whole camp.

Table IV

Falling Temperature

Calcite-quartz fissure filling veins

Fracturing

Tetrahedrite

Chalcopyrite

Pyrrhotite + Au

Pyrite + Au

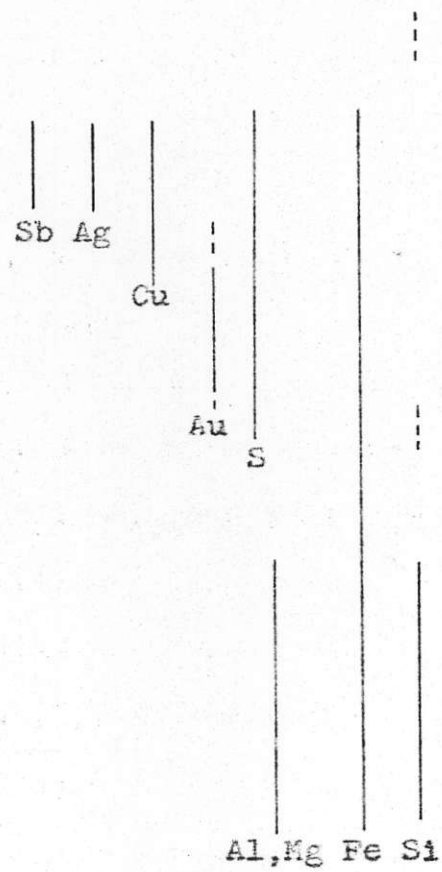
Calcite and quartz veins

Fracturing

Deposition magnetite (py, specularite) as replacements or fillings in breccia zones, with minor garnet, epidote, and actinolite

Brecciation, faulting, fracturing

Replacement of limestone by skarn minerals



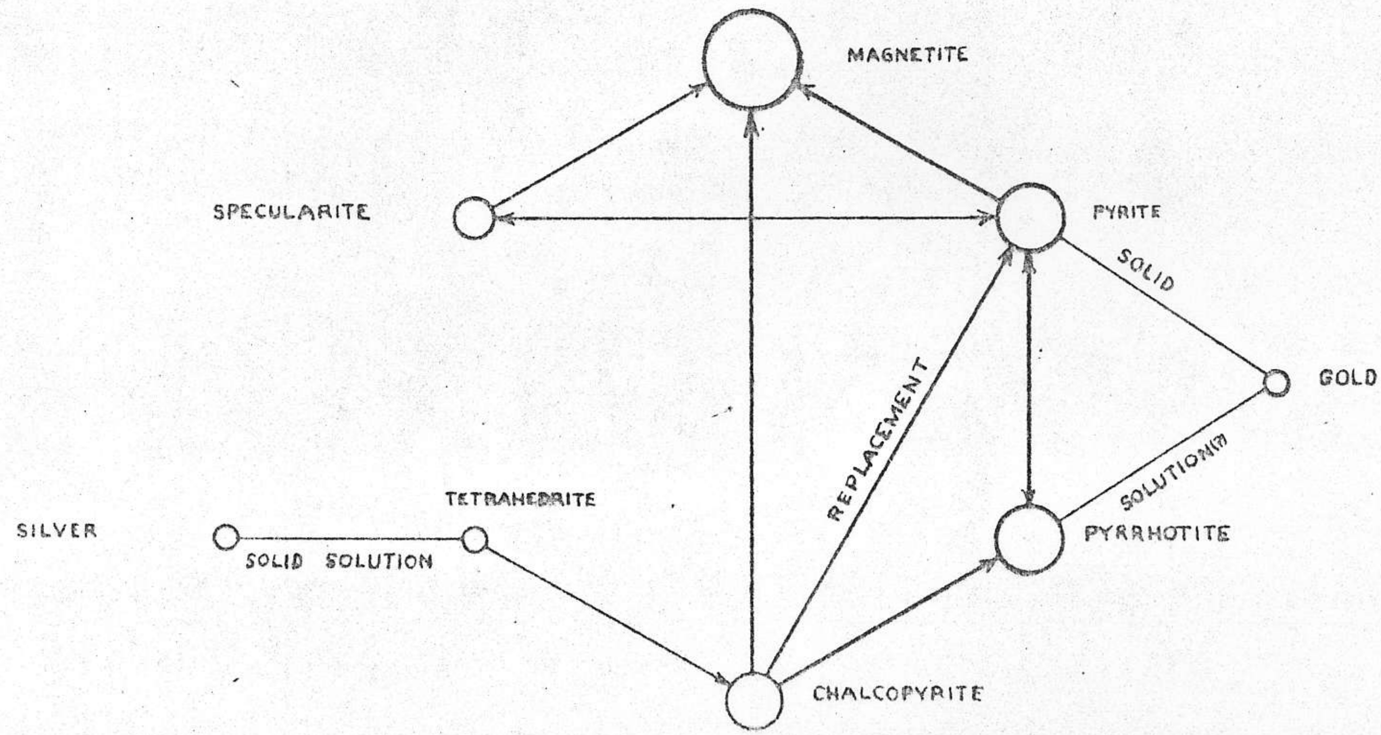

The mutual relations of the metallic minerals are shown in Figure 2.

## F. RELATIONSHIP OF SKARN DEPOSITS AND PRECIOUS METAL DEPOSITS OF THE BOUNDARY DISTRICT

The distribution of the precious metal deposits of the Boundary District is shown in Figure 1. As may be seen from the diagram, these ore deposits are distributed in country rock near the peripheries of granitic bodies, or in the granitic rocks themselves. No deposits of this type have been discovered in the Summit Camp. The veins occur in Eholt volcanics, Rawhide argillite, Knob Hill rocks, or granitic rocks. Precious metal deposits

FIG. 2.

PARAGENETIC DIAGRAM OF ORE DEPOSITION



are associated with limestone at only two places, and even here are not found in limestone. The vein deposits differ from skarn deposits in temperature of deposition, which was lower in the veins. Fissure filling rather than replacement is the typical mode of emplacement of the veins. Ore consists of chalcopyrite, galena, chalcocite, sphalerite, pyrite, tetrahedrite, ruby silver, argentite, gold, and tellurides in a gangue of calcite and quartz.

The production of the three main deposits is given in the following table.

Table V

| | Tons Shipped | Au (oz.) | Ag (oz.) | Pb (lb.) | Zn (lb.) |
|---|---|---|---|---|---|
| Providence | 11,451 | 5,867 | 1,361,433 | 400,288 | 258,100 |
| No. 7 | 15,152 | 2,971 | 99,987 | 213,926 | 13,727 |
| Dentonia | 95,884 | 23,731 | 157,620 | 344,856 | 403 |

It is evident that the veins were very rich, especially in silver.

It is suggested that these deposits are related to the final stages recorded in skarn deposits - deposition of chalcopyrite-tetrahedrite and filling of fissures and breccia zones by calcite and vuggy quartz veins. It is possible that the precious metal deposits represent a final low temperature stage of mineralization not strongly affected by assimilation of limestone by the magma. Fissures were produced in intrusive and country rocks, perhaps by cooling, and minerals were deposited in the fissures. The clustering of veins about and in granitic bodies may indicate that low temperatures of wall rocks and ore-bearing fluids permitted only short transport of metals before deposition.

Assimilation of $CO_2$ by the intrusive may have been the cause of the release of metals into skarn during an earlier stage of cooling of the rocks. Carbon dioxide may have acted as a flux that prevented early consolidation of the intrusive where it contacts limestone, thereby allowing early entry of mineralizing fluids.

G. AGE OF THE SKARN DEPOSITS

It is probable that the skarn deposits of the Summit Camp are due to the effects of granitic intrusions. Although the age of these intrusions is thought to be Mesozoic on the basis of correlation with similar intrusions of known age that occur outside the Summit Camp, the granitic rocks of the Boundary District may be of early Tertiary age. White (personal communication) and Brock (1902) suspect a Tertiary age for the skarn type of mineralization in the Boundary District. Their best evidence is the apparent localization of mineralization against pulaskite dikes. The writer feels that the occurrence at the Oro Denoro Mine of ore-controlling fault which is cut by a pulaskite dike indicates a pre-pulaskite age for mineralization in the Summit Camp.

## H. RECOMMENDATIONS FOR FURTHER SEARCH FOR ORE

The regional diagram (Figure 1) of the area shows that where bodies of limestone occur in the Camp, there is a possibility of finding ore. As yet, search for new orebodies buried beneath overburden has not been very successful. It is possible that blind orebodies may lie in the Brooklyn Formation below Eholt rocks or pulaskite flows. Close study of strongly pyritized and fractured Eholt rocks might provide a clue to underlying mineralization. More detailed mapping of all outcrop in critical areas might reveal the configuration of the Brooklyn-Eholt contact, which controls skarn formation in many deposits. Areas covered by Tertiary flows would not be so susceptible to geological interpretation of underlying structure, but deep-probing geophysical methods might allow evaluation of such terrain.

APPENDIX

# APPENDIX

The appendix contains descriptions of critical or typical thin and polished sections. In general, one or more typical thin sections from each major formation, some representative thin sections of skarn, and three of the most typical polished sections of ore are described.

## POLISHED SECTIONS

Polished Section 334 - Oro Denoro Mine

Metallic Minerals

Magnetite

Pyrite

Chalcopyrite

Specularite

Macroscopically the specimen is seen to be made up mainly of magnetite with some blades of specularite. Magnetite contains pyrite and remnants of garnet. Microscopically magnetite is seen to be intergrown with specularite. Euhedral pyrite crystals appear to replace gangue and magnetite. Pyrite occurs also as replacement veins along fractures in magnetite. Chalcopyrite occurs as parts of the same veins and as replacing blebs in garnet. Pyrite presents euhedral faces to chalcopyrite, suggesting that the pyrite may have been earlier.

Polished Section 371 - Mountain Rose

Metallic Minerals

Pyrite

Chalcopyrite

Tetrahedrite

Magnetite

Pyrrhotite

Macroscopically the section can be seen to be made up of pyrite cut by pyrrhotite veinlets in a gangue of skarn. The sulphides are cut by minute veinlets of chalcopyrite. Chalcopyrite occurs also as disseminations and blebs in an area containing many veinlets of the same mineral. Under the microscope remnants of magnetite can be seen in pyrite. Pyrite replaces a mineral interstitial to garnet as well as garnet itself. Chalcopyrite mineralization is related to an irregular fracture. Minute blebs of tetrahedrite occur in chalcopyrite.

Polished Thin Section 276 - Oro Denoro

Metallic Minerals

Chalcopyrite

Tetrahedrite

Magnetite

The section consists of fine-grained garnet skarn with some residual calcite. One-half the section is taken up by chalcopyrite containing remnants of calcite. A few grains of magnetite occur near the skarn-chalcopyrite contact. Minute blebs of chalcopyrite occur in fractures in garnet. The main mass of chalcopyrite is cut by minute fracture-fillings of tetrahedrite that contains inclusions of chalcopyrite which match the borders of the veins. Metallic minerals and skarn are cut by a quartz-calcite veinlet.

THIN SECTIONS

Thin Section 370 - Limestone Breccia (Brooklyn Formation)

In hand specimen the rock is seen to consist of rounded to subangular limestone fragments in a fine-grained calcite matrix. A thin section of the matrix shows that it is made up of carbonate grains .02 to .1 millimeters in diameter, and a few quartz, biotite, and chlorite grains. The section contains small rounded pebbles of banded chert and fine-grained limestone. A single large (two millimeters) crystal of carbonate occurs in the section.

Thin Section 265 - Tuff (Eholt Formation)

Macroscopically this rock simulates the appearance of a fine-grained massive shale or siltstone with a few greenish patches and a few small angular fragments. The rock is actually a fine-grained agglomeratic tuff containing the following minerals:

| | |
|---|---|
| Quartz | 20% |
| Calcite | 15% |
| Orthoclase | 10% |

| | |
|---|---|
| Clays | 45% |
| Magnetite | 1% |
| Angular aggregates of bladed clay minerals | 10% |

The matrix consists of a fine-grained felted mass of clay minerals with a few grains of orthoclase and magnetite. Angular fragments of quartzite up to four millimeters in diameter and fragmental aggregates of bladed clay minerals occur in the section. Clay minerals are stained by hematite. Calcite replaces the rock as veinlets and vaguely defined patches.

Thin Section 208 - Agglomerate (Eholt Formation)

In hand specimen the rock is seen to contain rounded to angular quartzite fragments in a tuffaceous matrix. In thin section the agglomeratic fragments (.1 to one centimeter diameter) are seen to have corroded borders and fracture fillings of tuff. The matrix is composed of the following minerals:

| | |
|---|---|
| Plagioclase (+ relief) | 30% |
| Clinochlore | 60% |
| Magnetite | |
| Quartz | 10% |

Quartz and plagioclase are corroded and altered to clinochlore.

Thin Section 251 - Quartz diorite (Emma Intrusive)

| | |
|---|---|
| Plagioclase - $An_{40}$ | 70% |
| Quartz | 15% |
| Biotite | 15% |

The texture is porphyritic, the phenocrysts being of plagioclase. Plagioclase is zoned in an oscillatory manner, and is strongly altered to fine-grained phyllosilicates. The fine-grained matrix of the rock consists of quartz and plagioclase.

Thin Section 210 - Quartz diorite (Lion Creek Intrusive)

| | |
|---|---|
| Quartz | 20% |
| Plagioclase - $An_{36}$ | 50% |
| Biotite | 10% |
| Hornblende | 20% |
| Magnetite | 1% |
| Chlorite | |

The thin section contains not only Lion Creek quartz diorite but also part of an inclusion of Emma diorite (see Plate II;b). The quartz diorite is coarse-grained and equigranular in texture. Hornblende and plagioclase are euhedral, whereas quartz is interstitial. Plagioclase crystals are zoned in an oscillatory manner, and are slightly altered to phyllosilicates.

Thin Section 212 - Pulaskite

| | |
|---|---|
| Albite | 15% |
| Riebeckite | 2% |
| Aegerinaugite | 2% |
| Cryptoperthite | 70% |
| Biotite | 5% |
| Chlorite | 2% |
| Nepheline | 5% |
| Magnetite | 2% |

The texture is porphyritic, feldspars forming phenocrysts. The matrix is medium-grained. Phenocrysts, aegerinaugite, and riebeckite are euhedral. Feldspars are in part altered to phyllosilicates. Magnetite occurs as anhedral grains in the groundmass.

Polished Thin Section 306 - Skarn (R. Bell Mine)

The specimen is of coarse-grained marble replaced by large euhedral crystals of garnet and pyrite. Under the microscope the following minerals are evident:

| | |
|---|---|
| Garnet | 40% |
| Pyrite | 20% |
| Carbonate | 30% |
| Quartz | 5% |
| Chlorite | 5% |

The green garnet crystals are anisotropic and concentrically zoned at their outer edges. Chlorite replaces garnet along fractures. Pyrite appears to replace the coarse-grained carbonate, but conforms to the boundaries of garnet crystals. Pyrite crystals are surrounded by granular quartz. Veinlets of granular quartz and calcite cut garnet (Plate III;a).

Thin Section 332 - Skarn (Jumbo Mine)

The hand specimen is of medium-grained green garnet skarn with patches of carbonate. Disseminated grains of magnetite and chalcopyrite occur, most commonly near calcite. Thin, irregular hematite veinlets cut skarn. Minerals evident in thin section are:

| | |
|---|---|
| Quartz | 2% |
| Garnet | 85% |
| Carbonate | 10% |
| Magnetite | |
| Chalcopyrite | |
| Hematite | |
| Antigorite | |
| Muscovite | |
| Epidote | |

Garnet occurs as euhedral crystals replacing carbonate. Quartz occurs as rounded grains in residual carbonate and with late carbonate in veinlets and patches that replace garnet. A few grains of an epidote replace carbonate. Antigorite occurs as rounded aggregates of radiating crystals near garnet in quartz, calcite, and to a lesser extent in garnet. Fine-grained magnetite is associated with antigorite. Opaque minerals replace carbonate but conform to the borders of quartz and garnet.

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# PLATE I

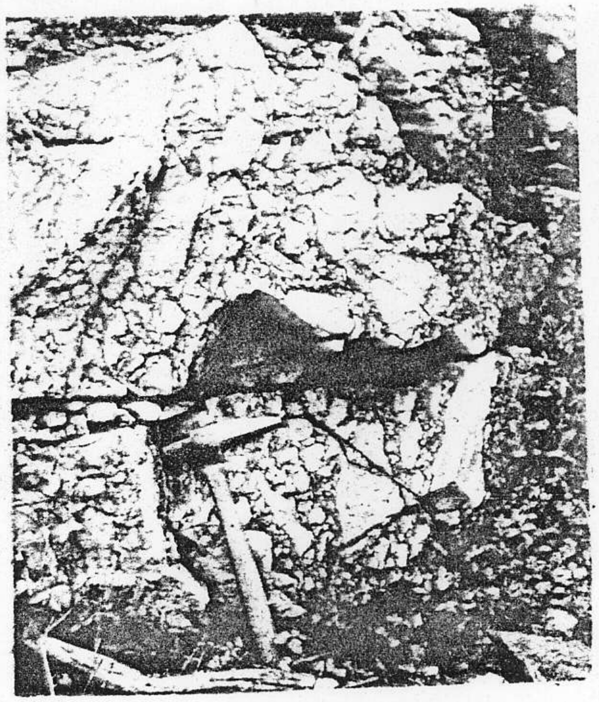
(a) Limestone breccia at Phoenix

(b) Limestone breccia from Lime Creek

(c) x 1/3 - Chert breccia

(d) x 1/2 - Chert conglomerate with silica overgrowth

# PLATE I



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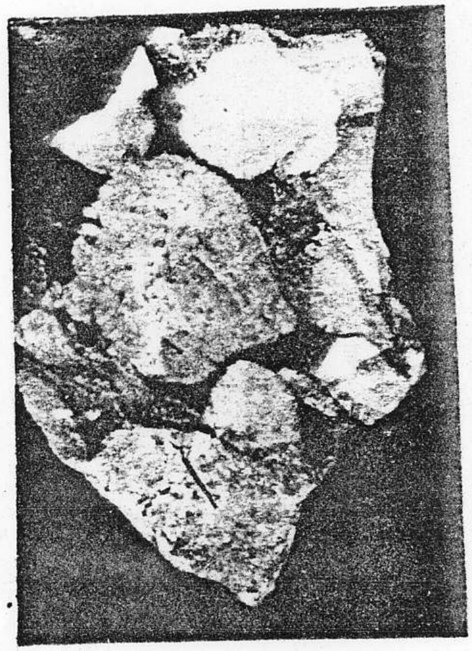

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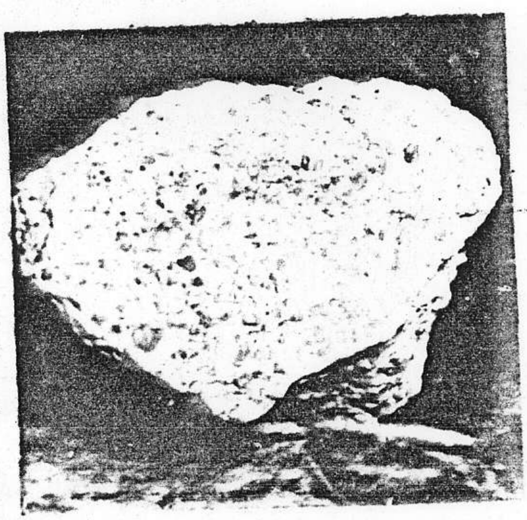

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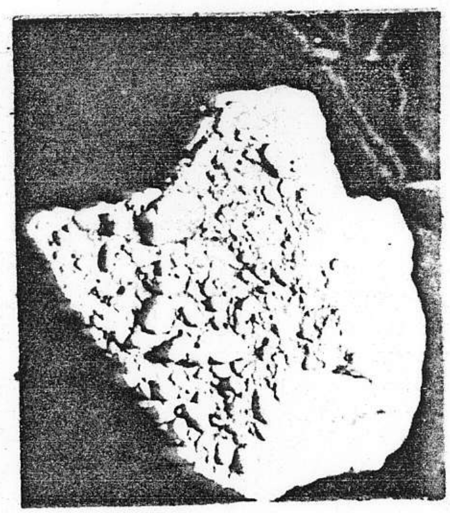

d

# PLATE II

(a) x 1/5 - Brecciated skarn fragments encrusted with magnetite, actinolite, and calcite - Swallow pit.
sk - skarn; mag - magnetite; act - actinolite; calc - calcite.

(b) x 1/2 - Rounded inclusions of Emma quartz diorite in Lion Creek quartz diorite.

(c) x 1/3 - Upper: Eholt agglomerate
Lower: Eholt water-lain agglomerate and tuff.

(d) x 1/2 - Pulaskite extrusive.

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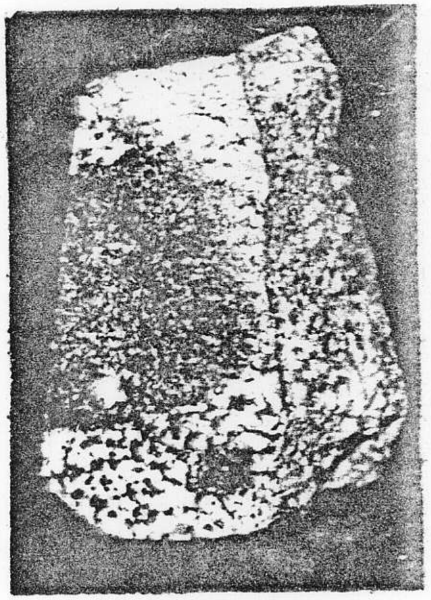
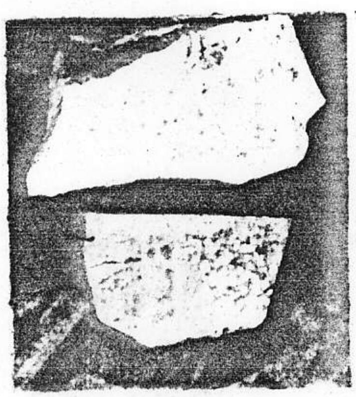
# PLATE II

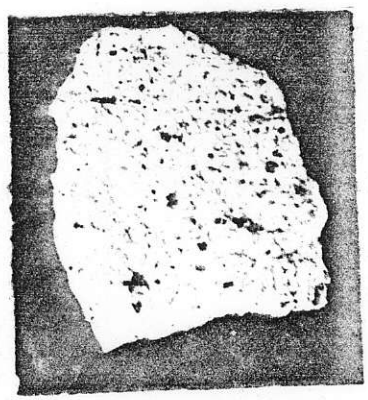

a



b



c



d

PLATE III

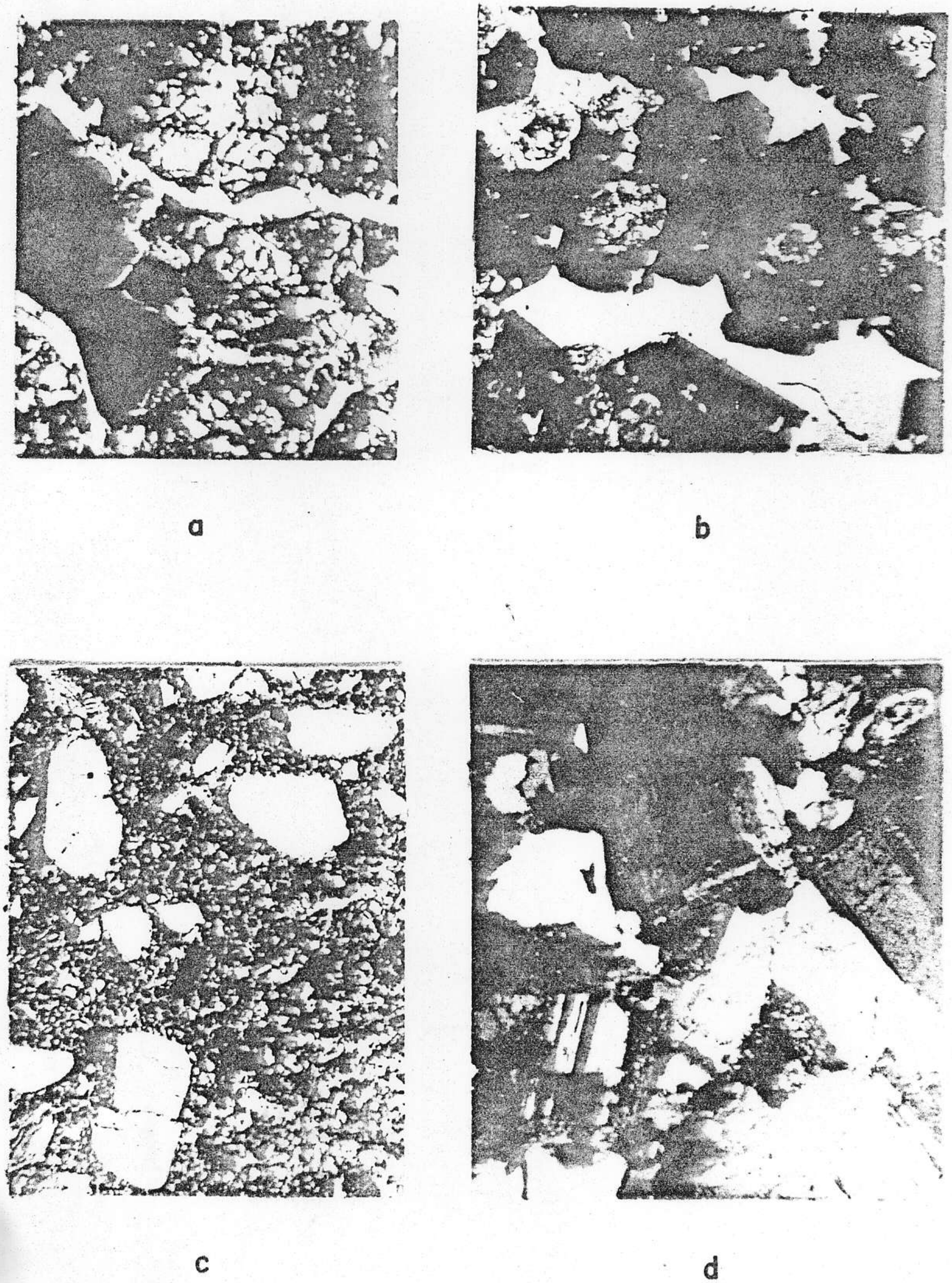
(a) x 13 - Photomicrograph; plane-polarized light: pyritized skarn from R. Bell Mine, showing cross cutting calcite veinlets.
Black - pyrite; grey - garnet; white - calcite.

(b) x 12 - Photomicrograph; plane-polarized light: magnetite ore from Emma Mine, showing unreplaced crystals of garnet and remnants of the calcite that magnetite has replaced.
Black - magnetite; grey - garnet; white - calcite.

(c) x 11 - Photomicrograph, plane-polarized light: chert conglomerate (same as shown on Plate I; d).
Chert pebbles in a calcite matrix.

(d) x 15 - Photomicrograph; X-nicols: Lion Creek quartz diorite.

PLATE III



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67
3

# Biographical Information

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PLACE AND DATE OF BIRTH: Aberdeen, Wash., U.S.A., Dec. 16, 1933

EDUCATION (Colleges and Universities attended, dates, degrees):

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POSITIONS HELD:

PUBLICATIONS:

AWARDS:

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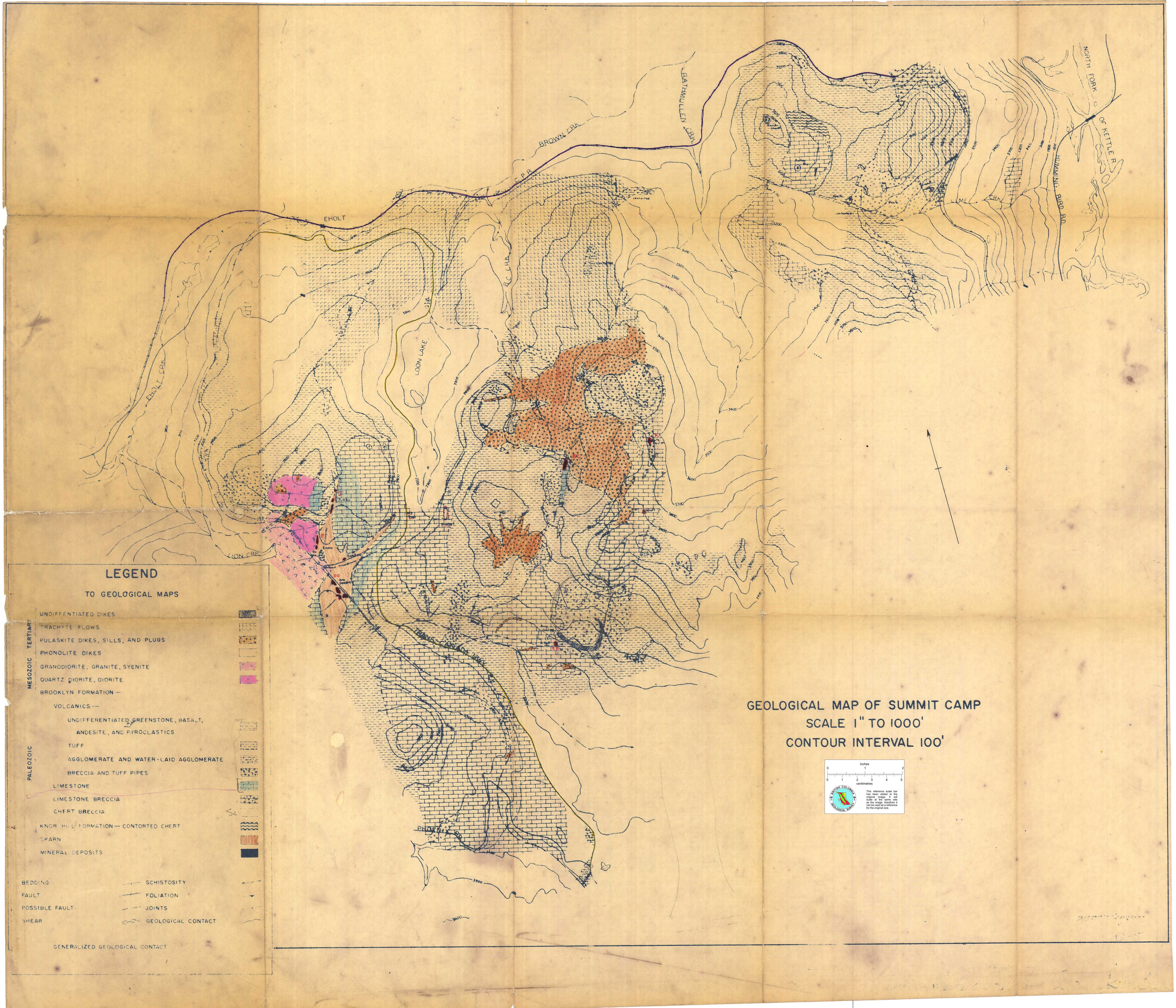
EHOLT
BROWN CRK
C.P.R.
LOON LAKE
EHOLT CRK
LION CRK
NORTH FORK OF KETTLE R.
HUMMING BIRD RD.
GEOLOGICAL MAP OF SUMMIT CAMP
SCALE 1" TO 1000'
CONTOUR INTERVAL 100'
inches
centimetres
LEGEND
TO GEOLOGICAL MAPS
TERTIARY
MESOZOIC
PALEOZOIC
UNDIFFENTIATED DIKES
TRACHYTE FLOWS
PULASKITE DIKES, SILLS, AND PLUGS
PHONOLITE DIKES
GRANODIORITE, GRANITE, SYENITE
QUARTZ DIORITE, DIORITE
BROOKLYN FORMATION —
VOLCANICS —
UNDIFFERENTIATED GREENSTONE, BASALT, ANDESITE, AND PYROCLASTICS
TUFF
AGGLOMERATE AND WATER-LAID AGGLOMERATE
BRECCIA AND TUFF PIPES
LIMESTONE
LIMESTONE BRECCIA
CHERT BRECCIA
KNOB HILL FORMATION — CONTORTED CHERT
SKARN
MINERAL DEPOSITS
BEDDING
SCHISTOSITY
FAULT
FOLIATION
POSSIBLE FAULT
JOINTS
SHEAR
GEOLOGICAL CONTACT
GENERALIZED GEOLOGICAL CONTACT