Geology of the Highland Valley
(unfinished draft, June 1969)

by J. M. Carr

Bethlehem
92I/SE1

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(c) Breccia from East Jersey orebody, drill hole No. B-82 at 156 feet, Bethlehem property. The close fit of fragments, and the sharp separation between fragments of one rock type and another (mostly hidden by scale) indicates brecciation was here restricted to fractures and flaws and caused little relative displacement of material.

(d) Breccia from Krain property (polished face). It consists mostly of sub-angular fragments of both aphanitic and aplitic porphyry (top centre) in a granular, locally foliated matrix mostly of partly broken quartz and feldspar crystals. A dark, fine-grained, altered rock fragment and an epidote-rich rock fragment occur at top right and bottom centre, respectively.

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(c) Breccia, East Jersey orebody, 775N drift on 4600 level. Here the breccia is coloured red by potash feldspar introduction. The fragments are mostly of the Guichon quartz diorite with some of porphyry and a few dark ones of unidentified rock type.

(d) Complex fracture zone, Ann No. 8 mineral claim, east of Gnawed Mountain. This rock is considered distinct from breccias described in the text. It consists of a single rock type (Bethlehem quartz diorite) which is strongly altered, chiefly by potash feldspar introduction, along numerous healed fractures of varied attitude. Quartz and specular hematite occur.

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(a) Guichon quartz diorite. Showing mainly subhedral plagioclase and poikilitic, wedge-textured quartz but with hornblende, biotite, and magnetite occupying most of the bottom-right. (X nicols).

(b) Bethlehem quartz diorite (porphyritic). Note portion of a sieve-like hornblende phenocryst (far right), chloritized biotite plates (bottom), microperthitic orthoclase (left centre, turbid after stain-treatment), zoned and partly turbid plagioclase, magnetite, and high-relief monazite (centre). Quartz shows white and irregularly shaped. (X nicols).

(c) Bethsaida granodiorite (stained section). Due to staining, orthoclase shows dark and plagioclase shows unnaturally turbid. Together with quartz these are the only minerals in view.

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(e) Breccia-forming quartz porphyry (P_3), aphanitic variety (as shown in Plate II, d). The visible crystals are plagioclase and quartz, with magnetite enclosed in the latter. (X nicols).

(f) Breccia-forming quartz porphyry (P_3), phaneric variety (aplitic P_3). Seen are an embayed quartz phenocryst, plagioclase phenocrysts and aplitic-textured, quartzo-feldspathic groundmass. Dark minerals do not show. (X nicols).

(g) Breccia-forming quartz porphyry, (Trojan rhyolite) (stained section). Dark crystals are orthoclase partly replaced by sericite, white crystals are quartz, light-grey areas are chlorite (filling vesicles and replacing hornblende crystals), and the high-relief crystal at upper right is monazite. (X nicols).

PHOTOGRAPHS (cont'd)

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(i) Breccia forming (?) quartz porphyry (aplitic brown porphyry at the north limit of the Trojan breccia pipe). Probably equivalent to the Krain porphyry. Strongly embayed quartz phenocrysts and turbid, altered plagioclase phenocrysts are conspicuous, as is the crudely aplitic nature of the quartzofeldspathic groundmass. (plane light).

(j) Breccia-forming quartz porphyry (Gnawed Mountain). Brecciated, chilled selvage with fragments of phenocrystic quartz (clear), plagioclase (turbid) and chloritized biotite (grey, streaky) in an aphanitic groundmass. (plane light).

(k) Crowded quartz porphyry. Chilled selvage of dyke cutting breccia at East Jersey orebody. Turbid plagioclase, resorbed quartz, and rare epidote, sphene, and magnetite are set in an aphanitic matrix (X nicols).

(l) Feldspar porphyry Type D. The 1-millimetre twinned crystal at upper centre and the small angular crystal nearby to the left are both hornblende; the other phenocrysts are plagioclase. The groundmass is an irregular mosaic mainly of plagioclase and quartz which is typical of this type of porphyry dyke. (X nicols).

(m) Breccia, Gnawed Mountain. Larger broken and fretted fragments mainly of quartz, potash feldspar, and plagioclase are scattered in an uneven fine-grained matrix largely of these minerals. Chlorite, sphene, and magnetite also occur. (X nicols).

(n) Breccia, Trojan mine (drill hole No. S-1 at 209 feet). Fragments mostly of quartz, plagioclase, and chloritized hornblende or biotite are scattered in a chloritic clastic, fine-grained matrix in which tourmaline rosettes are developed (plane light).

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18M (100)-B71-6824 (4)

K-feldspar (m) ?

PHOTOGRAPHS (cont'd)

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(a) Northerly view across Highland Valley showing Little Divide Lake and volcanic capped hills at the South Simons zone (Bethlehem property) and Forge Mountain, September, 1959.

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15M (100)-971-6924 (4)

Index maps

Fig 1 ?

CHAPTER I -- INTRODUCTION

The Highland Valley area is in southern British Columbia, in the Kamloops Mining Division about 20 miles southeast of Ashcroft and 130 miles northeast of the deep-sea port of Vancouver (see Fig. 1). The area, which measures approximately 50 square miles, is outlined on Figure 1 and lies at the centre of a widely mineralized region that is underlain by the Guichon Creek batholith. This batholith is at the north end of the so-called Nicola Copper Belt, a rich mineralized region extending northwards for a distance of 100 miles from the International Boundary and containing the large copper mines of Copper Mountain, Craigmont, and Bethlehem and the celebrated Nickel Plate gold mine at Hedley.

The respective locations of the Bethlehem and Craigmont mines are shown on Figure 1, which also shows the positions of other copper deposits in the Guichon Creek batholith numbered as follows:

1. Glossy
2. W D R
3. Krain
4. Imperial and Transvaal
5. Highland
6. Trojan
7. Dansey, or C L
8. OK and Alwin
9. Bethsaida
10. Victor
11. Dora Kay
12. Empire
13. Kathleen
14. Lornex
15. Jay No. 101
16. Jericho
17. Gnawed Mountain
18. Bornite Ridge
19. Fiddler
20. Jay
21. SHO
22. SS
23. Vimy
24. Aberdeen
25. Marb

Figure 1 - Index map showing location of the Highland Valley area (shaded) and the principal copper deposits in the Guichon Creek batholith

26. Eric
27. WIZ (No. 4 zone)
28. Nigger (location approximate)
29. Highmont
30. Yubet
31. Valley

Prospecting mainly for copper has gone on at Highland Valley since before the turn of the century and has resulted in minor production from isolated copper lodes and in current major production from the open-pit Bethlehem mine, which from 1962 to December 1968 shipped 185 million pounds of copper in concentrates.

The area has become an important porphyry copper camp containing established large low grade copper-molybdenum deposits which undoubtedly will be mined on the Bethlehem, Lornex, Valley, and Highmont properties; similar, if smaller, known deposits on various other properties; and relatively small and high grade copper deposits which may prove mineable on the Alwin property. The entire mapped area is occupied by mineral claims, which are currently formed into properties extending well beyond the area and shown mostly on Figure 2.

Figure 2 - Index map of Mining properties near Highland Valley as of 1966.

1. Bear (North Pacific Mines Ltd.)
2. Krain (North Pacific Mines Ltd.)
3. Lux, Cindy (Canzac Mines Ltd.)
4. W.D.R., Nona
5. Transvaal
6. Salmo Prince Mines Limited
7. Trojan (South Seas Mining Limited)
8. Sam (Burlington Mines Ltd.)
9. NIM (New Indian Mines Ltd.)
10. RAF, TAM, MER, JAC (Cleveland Mining & Smelting Co. Ltd.)
11. Beaver, Lodge, Dave, Outrider (Valley Copper Mines Limited)
12. JB (North Pacific Mines Ltd.)
13. EZZ (Alwin Mining Company Limited)
14. AL, IC (Continental Consolidated Mines Ltd.)
15. Bethlehem Copper Corporation Ltd.
16. BX (B.X. Mining Company Limited)
17. Eden, Ezra, Job, C.L. (New Indian Mines Ltd. & Vananda Exploration Ltd.)
18. Bethsaida, Tom, BL (Valley Copper Mines Limited)
19. Noranda Exploration Company, Limited

20. Victor (Consolidated Skeena Mines Ltd.)
21. Sheba (Peel Resources Limited)
22. April, UP (Red Rock Mines Ltd.)
23. Gaza Mines Ltd.
24. Jericho Mines Ltd.
25. Lake, Laken, etc. (T.C. Explorations Ltd.)
26. Lorex (Northlode Exploration Ltd.)
27. Lornex Mining Corporation Ltd.
28. Ken (Kennco Explorations, (Western) Limited)
29. Highmont Mining Corp. Ltd.
30. Ann (B.X. Mining Company Limited)
31. AM, IDE, etc. (Minex Development Ltd.)
32. Cal (General Resources Ltd.)
33. Bornite Ridge Mines Ltd.
34. Price (Oro Mines Ltd.)
35. BO (Benson Mines Ltd.)
36. Cris (General Resources Ltd.)
37. Yubet (Stellako Mining Co. Ltd.)
38. Chataway Exploration Co. Ltd.
39. Rio (Rio Tinto Canadian Exploration Limited)
40. Jae (Earlcrest Resources Ltd.)
41. Alamo (San Jacinto Explorations Limited)
42. Oro, M.M. (Oro Mines Ltd.)
43. Royal, Cana, R.C. (Royal Canadian Ventures Ltd.)

Properties mostly referred to in this report are those, shown on the accompanying geological map (Fig. 3), which existed in 1958 when mapping was mainly done, and they partly differ from the currently existing ones. Unfortunately the base map employed for part of the area lying south of Highland Valley has proved to be inaccurate according to more recent maps and surveys, and thus on Figure 3 the relative locations of the Lornex deposit and adjacent deposits are to some extent distorted. The base map employed to the north of Highland Valley is a composite one, utilizing partly a topographic map by Hunting Air Surveys Ltd. (now Lockwood Survey Corporation Ltd.) and partly Government planimetric maps.

ACCESS AND CLIMATE

Highland Valley is reached from Ashcroft by a public highway 27 miles long, which services the Bethlehem mine. A gravel road continues easterly to Guichon Creek and thence to Savona, Kamloops, or Merritt.

All these places are served by rail and all but Merritt lie on the main transcontinental road and rail routes. Kamloops is the nearest airport, and a landing strip for light aircraft has recently been built at Highland Valley. All the mining properties are accessible by roads, and recently a fair road has been completed southward from Highland Valley to join public roads on the south and east sides of the batholith. This road, which lies east of the mapped area, starts west of the Jericho camp and extends past Billy Lake to Chataway Lake, where it divides into a western road joining Highway No. 8 at Mile 14 east of Spences Bridge and into an eastern road reaching the Craigmont mine via Dot Lake and Broom Creek.

Being on the plateau the area has a more moderate climate than much of the "dry belt" country. Precipitation is about 25 inches, distributed fairly evenly throughout the year, and temperatures seldom reach much below zero in winter or above 90 degrees Fahrenheit in summer. Highland Valley is broad and flat, with small lakes, hay meadows, and marsh, and the surrounding hills are forested with jack-pine, Douglas fir, and poplar. There is no logging because the area is within the Nicola Forest Reserve. There are few permanent residents, most mine employees commuting from Ashcroft.

TOPOGRAPHY AND GLACIATION

The area is part of the Thompson Plateau, which is a moderately dissected unit of the Interior Plateau. Elevations range from 3,900 feet in Highland Valley to 6,400 feet on the north side of the valley at Forge Mountain, and nearly to 6,000 feet on the south side of the valley at Gnawed Mountain. The rolling surface of the Plateau which resulted from Tertiary erosion was modified strongly in detail by Pleistocene glaciation and recent stream action. Highland Valley itself is a flat-bottomed northwesterly valley as much as 1 mile wide and 15 miles long whose walls mostly rise steeply to the plateau surface at about 4,800 feet elevation. It contains two small misfit streams, Pukaist Creek and Witches Brook, which flow west and east, respectively, and are separated by a low divide on the valley floor at Quiltanton (Divide) Lake. Beyond Highland Valley the two streams flow rapidly through rock-cut canyons to Thompson River and Guichon Creek, respectively. According to Nasmith (1957), Highland Valley probably was part of a Tertiary drainage system on the interior plateau and became isolated high above general base level due to disruption of the system and to subsequent downcutting by the present major streams.

Pleistocene ice sheets moved south-southeastward over the area, scouring the bedrock surface and partly mantling it with glacial drift. On melting they left hummocky moraine and irregular gravel deposits strewn on the plateau surface, partly to depths of tens of feet. In the valleys, where ice tongues remained longest, meltwater channels were repeatedly cut in the walls and abandoned (for example, near the Trojan mine and the Lornex discovery zone); gravel trains were deposited along the edges of stagnant or shrinking tongues of ice; and a variety of stratified deposits filled the valleys to great depths. In Highland Valley a hole drilled vertically near the road, west of the Iona switchback, penetrated 857 feet of talus and other deposits without reaching bedrock. Holes drilled at a close spacing across the northerly valley leading to the Trojan mine reached the bedrock surface at greatly varying depths and so indicate the presence of buried canyons that were probably carved by meltwaters. Recent drilling of the Lornex deposit at Award Creek, south of Highland Valley, revealed that this subsidiary valley is mantled by superficial deposits as much as 250 feet thick, and holes drilled to explore the Valley deposit near Quiltanton (Divide) Lake revealed overburden as thick, in places, as 848 feet.

Bedrock exposures are mostly on the higher ground and probably amount to about 3 per cent of the whole area. Topography bears little relationship to the type of bedrock, except that Bose Hill and Forge Mountain owe their prominence to cappings, or cores, composed of Tertiary volcanic rocks. Straight topographic features abound in the area and are termed lineaments; the extent to which they are related to bedrock structure is uncertain but some at least are the expression of faults. Highland Valley itself mainly comprises two west-northwesterly lineaments, which are offset from one another at Divide Lake and may reflect a structural control of unidentified nature. Numerous lineaments in the area either are occupied by creeks and gullies or are faint, narrow features best seen on air photographs, and especially on recent black and white infrared photographs (e.g., Nos. B.C. 5312/1 to 45 flown August, 1968). They possess numerous different strikes and are partly in groups of parallel lineaments. Some northwesterly ones correspond with the direction of glacial grooving and may have less significance than do others. A few, faint northerly and northeasterly lineaments are proved by trenching and drilling to coincide with faults, and probably many other lineaments of various trends also represent faults. A northerly lineament extending through Quiltanton (Divide) Lake and recognized from air photos by N.D. McKechnie in about 1956 is now known to coincide closely with a fault on the west side of the Lornex deposit and possibly on the east side of the Valley deposit (<u>see</u> Ann. Rept., 1968, Fig. 20).

MINING HISTORY

Mining claims were recorded in the area as early as 1899, and by World War I, copper showings had been discovered on or close to many of the presently known major deposits. The names and locations of the principal claims held at that time are shown on a map in the Annual Report for 1915. Between 1915 and 1918, high-grade ore containing bornite was shipped from veins at the Snowstorm mine (on the present Bethlehem property) and the O.K. (Chataway) mine, the quantities being: from the Snowstorm, 136 tons yielding: Gold, 8 ounces; silver, 78 ounces; copper, 76,754 pounds, and from the O.K., 2,064 tons yielding: Gold, nil; silver, 869 ounces; copper, 529,748 pounds. A concentrator was built at the O.K. mine which, according to a later report, in 1916-17 treated about 10,000 tons of material containing approximately 3.6 per cent copper, from which 1,487.8 tons of concentrate (wet) was produced with an average assay of 20.33 per cent copper and 1.19 ounces silver (Minister of Mines, B.C., Ann. Rept., 1922, pp. 140-141).

In 1919-20 the British Columbia Department of Mines diamond-drilled eight holes totalling 5,736 feet on the Snowstorm claim and sampled widespread mineralization on the nearby Iona claim by means of an adit 280 feet long, a 40-foot shaft, and numerous shallow pits. Low copper prices discouraged further work and the area received little exploration in the period between the wars. In 1943, Ventures Limited did 2,778 feet of diamond-drilling in five holes, four being on the Iona claim and one on the Jersey claim south of the present Bethlehem mine.

Present-day activity began in 1955, when Bethlehem Copper Corporation Ltd. was formed to explore a large number of claims located previously by Messrs. H.H. Huestis, P.M. Reynolds, and J.A. McLallen.

The company trenched and bulk-sampled the Iona zone, the southern fringe of the Jersey orebody, and other showings before optioning the property to American Smelting and Refining Company Ltd. From 1955 to 1958, when the option was dropped, the latter company did 68,000 feet of diamond, rotary, and churn drilling that variously discovered and outlined the Jersey and East Jersey orebodies, investigated the Iona zone, and intersected mineralization at numerous other places on the property. In 1958 and 1959 Bethlehem Copper Corporation drove a mile-long adit with drifts and crosscuts in order to bulk-sample the Jersey and East Jersey orebodies. In 1960 the East Jersey orebody was further tested by raising and diamond drilling from surface and underground. In 1961, with the financial support of the Sumitomo group of companies of Japan, the company began preparing this orebody for open-pit mining.

Production began from the East Jersey orebody in November 1962, and a mill of rated capacity 3,400 tons per day was opened officially in February 1963. Concentrates were trucked to Vancouver for shipment to Japan under a 10-year exclusive contract. In 1964 capacity was increased to 6,000 tons per day. Up to February 1965, mining was almost entirely from this orebody and the total dry tonnage milled amounted to 2,941,968 tons with average heads of 0.971 per cent copper. Recovery was about 93 per cent and the grade of concentrate produced was about 42 per cent. The cut-off grade was 0.40 per cent copper and the stripping ratio of waste to ore varied during the life of the pit, from nearly 3:1 to as low as 0.5:1.

Beginning in March 1964, the company produced the first molybdenum concentrates to be made in British Columbia and, in the year ending February 1966, some 40,000 pounds of this metal was shipped to Japan from the mine.

In February 1965, with over 1 million tons of known ore in the East Jersey orebody remaining for future production, mining switched entirely to the Jersey pit and, in the year ending February 28, 1966, the dry tonnage milled amounted to 2,007,883 tons with average heads of 0.710 per cent copper. Recovery was 83.31 per cent and the grade of concentrate produced was 31.86 per cent.

The rated plant capacity was increased in 1966 to 10,000 tons per day and to 12,000 tons per day in late 1967, with mining and delivery of ore to the plant done henceforth by the company with new equipment instead of under contract. Production exceeded 40 million pounds of copper in the year ending February 1968 and 50 million pounds in the year ending February 1969. In that latest year the milling rate was 13,920 tons per day; mill heads graded 0.581 per cent copper; cut-off grade was 0.35 per cent copper; and the stripping ratio of waste to ore was 2.06:1 with the expectation that this ratio would shortly be reduced to 0.5:1 for the remaining life of the Jersey pit. At the end of that year, recovery was 85 per cent and copper concentrate grade was 35.2 per cent. Total production of the Bethlehem mine to the end of 1967 is recorded as: gold, 9,725 ounces; silver, 572,309 ounces; copper, 135,475,106 pounds; molybdenum, 93,995 pounds, all from 11,190,116 tons of ore milled. In February 1968 the company stated that, at a cut-off grade of 0.35 per cent copper, total proven reserves existing in the Jersey, Huestis, Iona, and East Jersey orebodies were 70,060,772 tons grading 0.60 per cent copper with an average waste to ore ratio of 0.73:1.

While the Bethlehem property underwent development the neighbouring properties received much attention, chiefly from small Vancouver-based companies but in some instances from major companies which obtained options. Between 1955 and 1958, surface and underground work was done on the Transvaal, Trojan, and Victor properties and surface work was done on the Bethsaida, Krain, and other properties. Large amounts of diamond drilling were done on the Trojan and Krain showings that indicated sizeable bodies of copper mineralization. Many parts of the area, mainly on the north side of Highland Valley but including the Bethsaida property on the south side, were covered by geochemical and geophysical surveys whose results are partly recorded in assessment reports filed with the Department of Mines and Petroleum Resources.

In 1958 and 1959 interest in the area slackened temporarily, in part due to the discovery of the Craigmont orebody near Merritt and a consequent, if unsuccessful search of that area for similar copper-iron skarn deposits.

Activity subsequently quickened in the Highland Valley and adjoining areas, and new finds of copper mineralization were made in 1962 on the Jay No. 101 claim and the A.M. and Ide claims of the Sheba and Highmont properties respectively, and in 1963 on the Jericho property. These and later developments are treated only briefly in this report because they post-date the main period of fieldwork and partly lie outside the described area, but they are more or less fully referred to in Annual Reports of the Minister of Mines. From 1964 onward the camp developed swiftly to its present importance, the principal events being:

1. The discovery by E.H. Lorntzsen in 1964 of showings that were subsequently extended and proved to be the huge Lornex deposit, which is scheduled for open pit mining starting in 1972 at the rate of 38,000 tons per day, under control of Rio Algom Mines Limited and The Yukon Consolidated Gold Corporation Limited. This orebody is stated, on the basis of surface and underground exploration

and sampling, to include 293 million tons containing 0.427 per cent copper and 0.014 per cent molybdenum.

2. The discovery in 1967 and subsequent underground exploration by Alwin Mining Company Ltd. of copper lodes near the old O.K. mine, amounting to as much as 1 million tons of material containing between 2 and 3 per cent copper on the evidence of work completed to 1969.

3. The discovery by Cominco in 1968 of a very large copper-molybdenum deposit lying immediately west of Quiltanton (Divide) Lake, mainly on the Valley Copper property and partly on the Bethlehem property. Company estimates based on drilling suggest that the Valley deposit contains 600,000 tons per vertical foot of material grading at least 0.4 per cent copper, exclusive of an estimated 200 million tons of roughly similar material within the Bethlehem portion of the deposit.

The period of these discoveries also saw work begun or renewed on properties throughout the area, and the finding of new copper occurrences on the Gaza, Cleveland, Chataway, Stellako, and other properties. The Trojan deposit was further explored by underground work and surface drilling; the Krain deposit was again drilled; and underground exploration and sampling accompanied surface drilling of the main Highmont deposit which, according to a company estimate made while work continued in 1969, includes 70 million tons of material with more than 0.3 per cent copper and appreciable amounts of molybdenum. In 1967 and 1968 at the Victor showing, chalcopyrite-bearing material was stockpiled for leaching and reduction in a pilot hydrometallurgical plant by companies, including Copper-Can Developments Ltd., which held a part of the Consolidated Skeena property on option.

PREVIOUS GEOLOGICAL WORK

Prior to 1955 no detailed geological investigations had been made of the Highland Valley area. The Guichon Creek batholith was shown in outline on successive maps of the Geological Survey of Canada and was briefly described together with some of its copper showings in the Nicola and Ashcroft memoirs which accompanied the latest of these maps (Cockfield, 1948); (Duffell and McTaggart, 1952). Duffell and McTaggart showed that in the vicinity of Ashcroft the batholith was emplaced between early Upper Triassic and early Middle Jurassic time.

The geologists employed in 1955 on the Bethlehem project gave an account of Highland Valley geology which described the geological setting and mineralogy mainly of the Bethlehem deposits and to some extent the Trojan, Krain, Victor, and Bethsaida deposits (White, Thompson, and McTaggart, 1957). These authors recognized a "Younger Complex" that intruded the Guichon quartz diorite and was said to comprise, in apparently decreasing order of age: (i) the Bethsaida granodiorite stock and its marginal or cupola phase, the Bethlehem quartz diorite; (ii) dacite porphyry dykes and irregular masses, partly marginal phases of the Bethlehem quartz diorite; (iii) quartz diorite porphyry dykes; (iv) breccia pipes formed by volcanic and sub-volcanic activity. The authors recorded that emplacement of the "Younger Complex" was followed successively by faulting, mineralization, and emplacement of andesite dykes and they recognized a structural association of porphyry intrusions, explosion breccias, and copper deposits. They also gave a valuable account of the paragenesis of the ore minerals and concluded that the deposits associated with breccia could be classified as xenothermal, or sub-volcanic, having been formed at shallow depths and high temperatures. The deposits were thought to be genetically related to the "Younger Complex", whose age from intrusion to final consolidation might range from Cretaceous to Tertiary.

From long experience at the Bethlehem property Coveney (1962) reviewed the geology of its deposits and emphasized the role played by faults in localizing geological structures and controlling mineralization.

An investigation of the geology of the Bethlehem deposits by Alan Wood (1966) resulted in a description which unfortunately ignores the field evidence for relationships that exist between various rock types near these deposits.

Since 1955, exploration of much of the batholith has resulted in numerous reports and geological maps covering various properties, many of which are on public file at the Department of Mines and Petroleum Resources (see lists of assessment reports in Minister of Mines, B.C., Ann. Repts., 1958 and subsequent years). Restricted marginal parts of the batholith in the Merritt and Ashcroft areas are described in reports by the writer (Minister of Mines, B.C., Ann. Repts., 1960 and 1962, respectively).

Geological reconnaissance mapping of the entire batholith by K.E. Northcote in 1964 and 1965 accompanied radiometric dating of the constituent rocks, partly by Northcote and partly by others (White et al., 1967; Northcote, Bull. 56, 1969). This work showed that emplacement of major and minor phases of the batholith occurred within a very limited time span, because all the dated rocks possess essentially the same absolute age, which is determined as 200 $\pm$ 5 million years. This date was obtained not only for the Guichon and Bethlehem quartz diorites and the Bethsaida granodiorite, but also for the P_3 porphyry and biotite in the Iona breccia (Dirom, 1965).

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork for this report totalled about 10 months between 1956 and 1960 and included full seasons in 1957 and also in 1958, when a senior assistant, Randolph Lee (now Dr. Randolph Lee, M.D.), completed the mapping of outcrops between showings on the north side of Highland Valley. Lack of time prevented similar outcrop mapping being done on the south side of the valley, where work was mostly confined to investigating and mapping the known showings. However, some further mapping was done by the writer in 1960 around the summit of Gnawed Mountain and was aided by geological maps provided by companies. From 1961 to 1968 further visits were made to the area in all years except 1965, and to some extent observations made at these times are incorporated in this report. Also incorporated are a few observations and comments relating to information available as recently as May 1970.

The writer gratefully acknowledges the indispensable help and co-operation received from the personnel of companies active in the area, especially for the provision of maps and information of all kinds. The very able assistance given in the field by Randolph Lee is acknowledged above. Field assistance was also given in various years by M. Mealing, A. Jellinek, W.L. Cousens, B.L. Barman, and the late L.S. Redivo. Thanks are also due to K.S. Crabtree for draughting the maps and figures and to W. Player for preparing numerous thin sections of rocks. R.V. Kirkham kindly did petrographic modal analyses of some rocks for this report.

CHAPTER II -- GENERAL GEOLOGY

GEOLOGICAL HISTORY OF THE GUICHON CREEK BATHOLITH

Geologically, the Highland Valley area is a central and highly diversified part of the Guichon Creek batholith. The batholith is 40 miles long, as much as 16 miles wide, and is shaped like a lozenge, being elongated in a direction slightly to the west of north and possessing rather pointed ends and facetted sides. It is emplaced mainly into Upper Triassic volcanic and sedimentary strata of the Nicola Group and locally on the west side into more or less similar Upper Palaeozoic strata of the Cache Creek Group. On its west and southwest sides it is emplaced locally into quartzite, schists, and gneisses whose ages are unknown (see Ann. Rept., 1962, pp. 35-37). At the Craigmont mine the Nicola strata are upturned at the south edge of the batholith, and near Ashcroft the Cache Creek and Nicola rocks occupy tilted fault blocks which are transgressed by the batholith. Chiefly at its margins the batholith is partly overlain by sedimentary and volcanic rocks that range in age from early Jurassic to Miocene. Structurally, the batholith occupies the position of a positive compound fault-block that is surrounded by grabens (Fig. 4) and, perhaps because of this weak structural setting, it has undergone repeated fracturing and intrusion.

The successive emplacement of intrusive bodies was probably partly controlled by fracturing of the batholith in response to movement on underlying block faults, whose existence is inferred from mapping near Ashcroft (see Ann. Rept., 1962, pp. 43-44). The distribution of the various intrusions in the batholith is more or less known, mainly from the work of company geologists and reconnaissance mapping by K.E. Northcote.

Figure 4. Sketch-map showing the regional graben pattern in southwestern British Columbia.

Older rocks predominate and are mainly quartz diorites of several varieties, which are probably not of precisely one age.* Diorite and dark,

*Rock naming in this report follows the present usage of the Geological Survey of Canada, whereby granite contains mainly K-feldspar, quartz monzonite has more or less equal amounts of both feldspars, and granodiorite and quartz diorite have mainly plagioclase feldspar. The two last-named rocks differ essentially only in the composition of their plagioclase and are impossible to separate in the field.

distinctly hybrid rocks, which contain abundant, partly assimilated xenoliths, show up on aeromagnetic maps and occur variously at the batholithic margins and as long screen-like bodies in the interior, where they probably separate and grade into successive intrusions of quartz diorite. Chilling has nowhere been observed at the limited exposed margins of the batholith. Gabbro which is reported near Mamit Lake (see Nicola memoir, p. 16) may be a local phase of the older rocks. In general, the older rocks are medium grained and possess a perceptible foliation that commonly is steeply aligned more or less parallel to the outlines of the batholith (see Chaplin, 1958, map No. 3). In common with the later rocks, they contain aplite dykes but rarely ones of pegmatite, suggesting that the rocks either were "dry" or failed to entrap volatiles released by their crystallization. Some of the older quartz diorites may have been emplaced later than others because they possess a porphyritic tendency, a complex zoning of plagioclase, and other petrographical features resembling those of the younger rocks in the batholith. In the Highland Valley area two varieties of the older quartz diorite are present, of which the Beaver quartz diorite may be later than the Guichon quartz diorite. On Northcote's map the Beaver quartz diorite is shown as part of the Bethlehem quartz diorite.

A younger quartz diorite grades in places to quartz monzonite and comprises numerous bodies, both large and small, which occur widely both in and partly beyond the batholith. Probably the largest body is one that extends across the present area from south of South Forge Mountain to Gnawed Mountain and also persists farther southeastward to beyond Roscoe Lake for a total known distance of 11 miles. Its western margin, which is separated from the main mass of this body by a later stock of granodiorite, extends southward through points east of Calling and Pimainus Lakes, respectively. In the southeastern part of the batholith other, incompletely mapped bodies occur near Gypsum and Farr Lakes, respectively, and in the southwestern part another large body occurs on the west flank of Skwilkwakwil Mountain. Other bodies near Basque and at Jesse Creek, near Merritt, resemble the latter body in being of quartz monzonite; they lie partly and wholly outside the batholith, respectively (<u>see</u> Minister of Mines, B.C., Ann. Rept., 1962, pp. 39 and 56). The one near Ashcroft is structurally interesting because it is emplaced apparently between fault blocks at the edge of the batholith (op. cit., p. 44).

The younger quartz diorite, or quartz monzonite, is generally a more or less porphyritic rock whose average grain size ranges from rather fine grained to medium grained according to the size of the body and the degree of its chilling, which is never extreme. In the present area this rock is named the Bethlehem quartz diorite and it includes a variety popularly termed the Skeena quartz diorite. On the Bethlehem property the Bethlehem quartz diorite encloses a small, related body of granite and quartz monzonite which is named the Bethlehem granite and regarded as part of the younger quartz diorite intrusions.

A central, apparently later stock of the Bethsaida granodiorite is emplaced mainly, if not entirely, in the Bethlehem quartz diorite. The stock has an average width of about 5 miles and it extends southward a distance of 12 miles from the Bethsaida property to Skuhun Creek. Its contacts are largely hidden, and to within short distances of them the granodiorite retains a medium-grained, somewhat porphyritic appearance.

Minor intrusions in the batholith are chiefly dykes that include dacite and other porphyries of pre-mineral age and post-mineral lamprophyres and andesites. The porphyry dykes occur principally in the Highland Valley area, where they form a swarm 10 miles long whose width decreases northward from about 5 miles to less than 3 miles (Fig. 5). The swarm is at least partly later than the stock, since some of its dykes cut the Bethsaida granodiorite. Some dissimilar porphyry dykes occur separately to the east of the main swarm, partly within the mapped area. Dykes at Gnawed Mountain may continue southward beyond the area and others occur farther southeast in the region of Roscoe, Chataway, Dot, and Gypsum Lakes. A porphyry dyke similar to those at Gnawed Mountain is reported to trend northeastward south of Calling Lake, near the Kathleen shaft (K.E. Northcote, pers. comm., and see Assessment Report No. 750, Map No. 1). Porphyry dykes occur in quartz monzonite at the western margin of the batholith near Basque and outside the batholith at Jesse Creek, and are of quartz latite and latite, respectively (Minister of Mines, B.C., Ann. Rept., 1962, pp. 39 and 56). Porphyry dykes of dacitic composition are emplaced in country rocks outside the batholith west of the Craigmont mine and near Ashcroft, respectively (Minister of Mines, B.C., Ann. Repts., 1960, p. 35; 1962, pp. 40-41).

Breccias were formed simultaneously with some porphyry dykes at Highland Valley and are intrusive bodies partly of considerable size.

They occur roughly at the localities shown on Fig. 5. Similar breccias are known elsewhere only outside the batholith; for example, at Jesse Creek and several miles to the west of the Craigmont mine, respectively, where the breccias are likewise associated with porphyry.

Post-mineral dykes include brown porphyritic andesites in the southwestern part of the batholith. These may well relate to a suite of such dykes cutting volcanic rocks of the Spences Bridge Group, which flanks that part of the batholith and whose assigned age is Lower Cretaceous (Aptian). Post-mineral dykes at Highland Valley include light-coloured andesites (leuco-andesite of White, Thompson, and McTaggart, 1957), which may chiefly occupy mineralized faults and closely resemble post-mineral dykes in areas such as Brenda Lake, Endako, and Promontory Hills near the Craigmont mine. In the latter area the dykes cut volcanic rocks assigned to the Kingsvale Group, whose minimum age has been determined radiometrically as 80 million years (Upper Cretaceous) although micro-fossils in the underlying sedimentary rocks are thought to indicate a Tertiary age (pers. comm. from Dr. G.E. Rouse, 1961; also see Geol. Surv., Canada, Paper 62-17, p. 19; Ann. Repts., 1960, p. 35; 1961, p. 33). One of the dykes at Highland Valley is reported to have an isotopic age of 50 million years, (White et al., 1967, p. 689) indicating an Eocene age and agreeing with the field observation that the dykes closely resemble some of the lowermost lavas on Forge Mountain in general composition and appearance. In common with local post-mineral basalt dykes on Forge Mountain, the light-coloured andesite dykes are therefore regarded as the intrusive expression of the Kamloops Group of lavas, specimens of which from north of Highland Valley have been variously dated as 45 million years and 49 million years (see map, Geol. Discussion Club Guidebook, Vancouver, 1960, revised 1968).

As in many other camps, lamprophyre dykes occur mainly in faults and at Highland Valley are virtually unmineralized. They may be earlier than the light-coloured andesite dykes, although this relative age is unconfirmed.

The ages of the chief intrusive rocks forming the batholith have been studied recently by White and his co-workers, with the result that the Guichon quartz diorite, the Bethlehem quartz diorite, the Bethsaida granodiorite, the P_3 porphyry, and biotite in breccia on the Bethlehem property all provide a radiometrically determined age of 200 million years (White et al., 1967). This absolute age must be accepted as uppermost Triassic or lowermost Jurassic, since the older rocks visibly intrude Upper Triassic strata and are overlain by early Jurassic conglomerates near Ashcroft (<u>see</u> Ashcroft memoir, p. 79; Ann. Rept., 1962, pp. 37-39; Frebold and Tipper, 1969).* Moreover, the conglomerates contain boulders of the Guichon quartz diorite and pebbles of dacite porphyry and other rocks, including porphyritic quartz diorites that bear a partial resemblance to the younger quartz diorite. No debris was found of the Bethsaida granodiorite, whose absence from the conglomerates may indicate that its stock remained roofed in the Middle Jurassic. The porphyry dyke swarm at Highland Valley was apparently emplaced scarcely later than the chief intrusive rocks, at the close of the Triassic period, because the dated biotite is in breccia that formed simultaneously with porphyry.

* Having re-examined fossil collections from the oldest fossiliferous Jurassic strata near Ashcroft, Frebold and Tipper (1969) concluded that these strata and the underlying conglomerates together represent the first two stages of the Lower Jurassic (Hettangian and Sinemurian) and that the batholith was emplaced in the uppermost (Rhaetian) stage of the Triassic.

The age of copper-molybdenum mineralization at Highland Valley lies somewhere between 200 million years and 49 million years, or between the Triassic and Eocene. White and his colleagues (1967, p. 682) consider that biotite in mineralized breccia at the Bethlehem property is hydrothermal and that the associated mineralization has a similar age to the biotite, that is, 199 million years as determined. Boulders in the Middle Jurassic conglomerates were examined for evidence of contained mineralization and all that was found was pyrite, apparently of hydrothermal origin, in porphyry pebbles that are not necessarily from within the batholith. The Craigmont orebody is apparently the same age as the batholith, namely 198 million years, according to rubidium-strontium dating of K-feldspar associated with chalcopyrite in veins at Craigmont (see Chrismas, et al. 1968).

Fracturing and faulting are probably concentrated in certain parts, areas, or belts of the batholith, perhaps largely in response to stresses imparted by fault movements in the underlying or surrounding country rocks (see Carr, 1969). Present mapping is not sufficiently advanced to allow complete recognition of the extent of the probable belts of fracture and deformation. Fracturing of each intrusive body probably began as soon as the newly emplaced rock was sufficiently cooled and consolidated to sustain brittle deformation, and it may have proceeded in successive stages more or less accompanied by rock alteration and in places by faulting. Faulting may have dominated later in deformation of these rocks, though possibly not until after mineralization. Recently, evidence suggests that important lateral movements have occurred on faults subsequently to mineralization (see Minister of Mines, B.C., Ann. Rept., 1968, Fig. 20). Even now, few faults in the area are located precisely enough to show on a detailed, factual geological map. Other faults could be surmised which may be represented by some of the many topographic lineaments that are visible on topographic maps and air photographs of the area.

GUICHON QUARTZ DIORITE

This chief representative of the older rocks is restricted on the map (Fig. 3) to the north side of Highland Valley, where it underlies much of a large area lying east of a line that extends north almost to the Trojan mine and thence northwestward. To the west its contact with the Beaver quartz diorite is obscured by overlying Tertiary lavas and by superficial deposits. To the east, not far beyond the mapped area, it apparently grades to darker quartz diorites and diorites which occur east of a line extending more or less northward through a point about 1 1/2 miles east of B.X. Lake. To the south it gives way on the Bethlehem property to a large younger intrusion of the Bethlehem quartz diorite, and farther east, roughly along Witches Brook, to a different variety of the older quartz diorite named the Chataway quartz diorite, which is exposed only beyond the present area (<u>see</u> Northcote's map). A former extension of the Guichon quartz diorite to the south is indicated by its occurrence as fragments in a breccia on Gnawed Mountain. To the north the rock probably extends beyond the mapped area but is largely hidden by superficial deposits.

The Guichon quartz diorite forms massive outcrops of a light grey colour and has a generally uniform appearance except where altered. It is a moderately dark, equigranular and medium-grained rock with a weak, perceptible foliation that is due to alignment of crystals principally of plagioclase and, to a lesser degree, of hornblende. The foliation is generally steep and from place to place it varies widely in strike about north. Joints are variable in attitude and belong to several sets, of which one appears more or less to follow the foliation and others may relate partly to adjacent faults, near which these joint sets become stronger and more closely spaced. The rock contains scarce inclusions, as much as 1 foot across, which are more or less rounded and are composed of a dark, fine-grained dioritic rock rich in hornblende and biotite. The quartz diorite is cut rarely by narrow, pale-coloured aplite veins and, in some places, more plentifully, by pink aplite veins which mainly occur close to younger intrusions.

The Guichon quartz diorite is distinguished from other rocks by the following features, which are visible either with the unaided eye or under a pocket lens:* (1) A coarsely speckled appearance, which results from the even distribution of dark minerals as irregularly shaped aggregates (Plate Ia); (2) the wedge texture of quartz (Fig. 6 and Plate Va): (3) a lack of oscillatory zoning in plagioclase. The light minerals in the rock are clear quartz, white or grey plagioclase feldspar, and pink orthoclase feldspar. The dark minerals are chiefly black biotite and dark green hornblende. Present in small amounts are the accessory minerals apatite, magnetite, sphene, monazite, and zircon. The rock texture is hypidiomorphic-granular, with plagioclase and hornblende occurring mostly as fairly well-shaped crystals and quartz, orthoclase, and biotite mostly as irregularly poikilitic or enclosing masses. This texture suggests that the rock consolidated from an initial spongy mass of crystals some of which, by additions from the crystallizing liquid, attained a poikilitic habit.

* In all Highland Valley rocks, the textural relationships of the feldspars, quartz and fine-grained groundmass, if present, are more readily seen if the surface to be examined is first wetted.

The average crystal size is 2 millimetres and crystals of either plagioclase or hornblende larger than 4 millimetres are rare. Poikilitic masses of either orthoclase or biotite are as much as one-half a centimetre wide, while poikilitic quartz is continuous in some cases for a distance of 1 centimetre. Orthoclase contains microscopic intergrowths of albite and is therefore microperthite. Plagioclase shows a gradual interior zoning and a stronger marginal zoning; according to optical measurements it ranges in composition from An_{35} to An_{45} and is therefore andesine. A modal analysis of typical Guichon quartz diorite is given in Table I; the specific gravity of 2.76 is the highest measured of Highland Valley rocks (Table II). Some variation in the relative proportions of the mineral components is apparent from place to place; thus hornblende may exceed biotite in amount although their total is fairly constant at about 15 or 20 per cent by volume of the rock. In the northern and eastern parts of the area the rock contains more orthoclase than elsewhere, having as much as 20 per cent of this mineral. In these parts, too, the rock exhibits a slightly different texture, its quartz being partly more open-textured with occasional compact areas or "eyes", and the dark minerals being less aggregated. Southeast of the Highland shaft, near the Novak road, these textural differences are so pronounced that the outcrops may in fact belong to the Beaver quartz diorite.

BEAVER QUARTZ DIORITE

Named after a group of former mineral claims, the Beaver quartz diorite occupies the southern and western slopes of South Forge Mountain and is confined on the south by the Bethlehem quartz diorite and overlain to the north by Tertiary lavas. To the east, a contact with the Guichon quartz diorite is hidden under deep overburden and is located approximately by examination of the cuttings from a number of rotary-drill holes. To the west, the Beaver quartz diorite may extend in drift-covered terrain beyond the limit of present mapping.

This quartz diorite is placed with the older rocks because it is apparently intruded by the Bethlehem quartz diorite. It nevertheless shares some petrographical features with the latter and so is considered to be intermediate in age between the Guichon and Bethlehem quartz diorites. It resembles the Guichon quartz diorite in forming massive outcrops which are traversed by rare pale aplite veins and also by joints of variable spacing and attitude; in being medium grained; and in possessing a weak foliation, which, where recorded, is all northerly and steep. It differs from the Guichon quartz diorite in the following field characters: (1) It is lighter-coloured because of lesser quantities of dark minerals (see the modal analysis, Table I) and consequently has a lower specific gravity (see Table II); (2) the dark minerals are mostly as separate crystals, not aggregates; (3) it is somewhat porphyritic due mostly to the presence of infrequent, well-shaped hornblende crystals whose size partly exceeds one-half centimetre; (4) these hornblende crystals have a sieve-like appearance, being more or less riddled by small enclosed crystals of plagioclase and quartz; (5) quartz has an open texture (Fig. 6b) and is also partly in compact, shapeless masses of "eyes" whose size reaches 3 millimetres; (6) biotite is not as generally poikilitic and it partly forms well-shaped plates and books of size as much as 3 millimetres; (7) plagioclase has oscillatory zoning, which may be visible under a pocket lens. Other textural and compositional features of the rock are generally similar to those of the Guichon quartz diorite. Orthoclase in the rock is microperthitic and is rather inconspicuous because of its pale colour and its division into small poikilitic areas, which are seldom larger than

1 millimetre and partly occur as narrow rims on plagioclase crystals. According to optical measurement the bulk of the plagioclase is calcic andesine, of composition between An_{40} and An_{50}, which is mantled by a more sodic plagioclase that is probably oligoclase.

BETHLEHEM QUARTZ DIORITE

This unit, known also as the younger quartz diorite, comprises part of a main body and numerous other smaller bodies in the area. The main body extends beyond the area as a stock that is elongated parallel to the batholith in a north-northwesterly direction. Its centre is occupied by the Bethsaida stock, whose age is probably later. The western edge of the main body lies west of the area and it extends northward probably through a point about 3 miles west of Indian Reserve No. 12. The eastern edge extends northward under cover from a point about 2 miles east of Gnawed Mountain; it enters the area near Indian Reserve No. 14 and thence crosses the Bethlehem property to the Beaver claims with an irregular, northwesterly trace. Any further extension of the body in this direction is unknown. Within the area the main body is emplaced variously in the Guichon and Beaver quartz diorites. The smaller bodies are scattered throughout the north and northeast parts of the area at distances of as much as 5 miles from the main body. They are partly irregular bodies and partly large dykes which trend predominantly west of north and are all emplaced in the Guichon quartz diorite.

The main body consists mostly of weakly porphyritic, medium-grained quartz diorite which persists in places to within short distances of the edge of the body; for example, on the Beaver group and along the western edge outside the area. At these places, any finer grained rocks that form the edge of the body are hidden by covered intervals all as much as 200 feet wide. In contrast, on the Bethlehem property the edge of the main body is partly well exposed and is formed partly of finer grained rocks, mainly porphyritic quartz diorite and a distinct phase, the Bethlehem granite. The smaller bodies consist mostly of porphyritic quartz diorite more or less similar to that of the main body on the Bethlehem property. At some contacts the porphyritic quartz diorite grades to an unusual marginal type known as the contact quartz diorite, which locally forms separate small bodies.

The attitude of all the various bodies is generally unknown, except on the Bethlehem property where numerous wedges and sheets project from the main body at all attitudes. At the Jersey orebody the Bethlehem quartz diorite forms a basin-like surface beneath the older rocks and a similar shape may obtain for a body partly underlying the Krain deposit (see Figs. 9 and 19). In detail, contacts tend to jog and shift in attitude and they appear partly to follow locally the directions of joints in the Guichon quartz diorite. The degree of chilling evident at the contacts on the Bethlehem property varies; none is apparent south of the East Jersey orebody, where an unusual variety of the medium-grained Bethlehem quartz diorite exhibits a pronounced crystal alignment of hornblendes parallel to the steep adjoining contact. On the 4600 level to the west of the Jersey orebody, the porphyritic quartz diorite appeared to show no chilling against the Guichon quartz diorite. In contrast, on surface to the east of the Iona zone and at other similar contacts seen elsewhere in the area, the porphyritic quartz diorite shows an increasingly finer grain within 2 feet of the contact, which is commonly occupied by a one-half inch wide selvage of pink granophyric quartz monzonite, representing the edge of the younger rock and possessing an average grain size of about one-half millimetre. Contact metamorphic effects in the adjacent Guichon quartz diorite are not definitely evidenced, being hard to tell apart from hydrothermal alteration, but effects such as silicification and a partial recrystallization of this rock near some contacts on the Bethlehem property may be due at least in part to metamorphism. As already mentioned, in places pink aplite dykes increase in numbers in the older rock toward the bodies of younger quartz diorite and so may be injections from the latter.

The Bethlehem quartz diorite forms pale-coloured outcrops in which the spacing of joints varies considerably, partly being close enough to divide the rock into narrow slabs and prisms. The rock contains a few inclusions which are much like those in the older rocks and it mostly possesses a weak, scarcely perceptible foliation, or crystal alignment, that has not been systematically mapped. It is cut by aplite dykes, no different apparently from those in the older rocks, and which are either white and as much as 4 feet wide or pink and more numerous and narrower.

Compared to the older quartz diorites the rock is distinctive in the field due to the following assemblage of features:

(1) Its light colour (dark minerals generally amounting to less than 10 per cent).

(2) Dark crystals separated discretely and not aggregated.

(3) Its more or less porphyritic appearance, principally due to occasional large hornblendes and plagioclases.

(4) Well-shaped hornblendes, partly as large sieve-crystals and partly small needles.

(5) Compact, small plates and books of biotite, which is not poikilitic and mostly either equals or exceeds hornblende in amount.

(6) Complex plagioclase zoning, seen usually with a pocket lens.

(7) Distinctive shapes of quartz, partly as phenocrystic "eyes" and partly in either dappled or open texture (<u>see</u> Fig. 6, b and c).

Other distinctive features may also be present, including pink orthoclase rims partly surrounding the plagioclase crystals.

Typical medium-grained quartz diorite occurs on either side of the Bethsaida stock to the south of Highland Valley where it used to be known as the Skeena quartz diorite. Where fresh it forms light-coloured, massive outcrops in which the rock has a light grey to pinkish cast and is speckled by dark minerals (<u>see</u> Plate 1b). A porphyritic nature is evidenced chiefly by dark, rectangular outlines of hornblendes as much as 1 centimetre in size which appear sieve-like due to the inclusion of numerous small plagioclase grains. On close examination these hornblendes also include grains of other components of the rock such as biotite, magnetite, and rarely quartz. Besides hornblende, other large crystals in the rock are variously of plagioclase feldspar, quartz, and biotite. The plagioclase phenocrysts reach one-half centimetre in size and are well shaped, as is usual for this mineral in all the Highland Valley rocks. Quartz phenocrysts are 4 millimetres in size and, although they retain a discrete appearance, they may totally enclose minute plagioclase grains and their outlines are partly ragged due to addition of late-crystallizing quartz. Biotite phenocrysts are 4 millimetres wide and are euhedral short books and plates. Excepting phenocrysts, which may amount to perhaps 20 per cent of the rock, the remaining crystals range widely in size from one-half millimetre to 3 millimetres, giving an inequigranular appearance to the rock under close examination. The texture is hypidiomorphic-granular, with abundant well-shaped crystals variously of plagioclase, hornblende, and biotite being surrounded by others, chiefly of quartz and orthoclase, which are poorly shaped and are adapted to fit between the well-shaped ones. Quartz is distinctly granular, the phenocrysts being seen under the microscope to consist of aggregated grains which formed probably due to inversion of a single individual during cooling of the rock. The overall quartz texture ranges between the dappled and open textures which are illustrated, and the open-textured quartz comprises interlocking grains of size mostly between one-half millimetre and 1 millimetre. Orthoclase is pink and mostly non-perthitic and, although partly occurring as interstitial grains and as rims on the plagioclase crystals, it is seen microscopically in places to enclose other minerals in poikilitic texture and also to be intergrown coarsely with quartz. Plagioclase has a zoning more complex and with more numerous reversals than that in plagioclase of the Beaver quartz diorite, and the crystals have wide margins whose composition is as sodic as oligoclase. The optically measured compositions of the interiors of crystals are as calcic as andesine (An_{40}). Although most biotite is well shaped, a certain amount of this mineral has a shreddy, interstitial habit due to its late crystallization. Accessory minerals in the rock are those common to most Highland Valley rocks; they include apatite, magnetite, sphene, and monazite which are scattered as mostly well-shaped small grains of early crystallization. The typical medium-grained rock has a mineralogical composition, or mode, which is generally similar to that given in Table 1 for the finer grained porphyritic quartz diorite, although medium-grained rocks on the Lornex property may show as much as 15 per cent by volume of dark minerals instead of the lesser amounts which are more generally present. The typical rock has a measured specific gravity of 2.69, which is close to that of other principal varieties of the Bethlehem quartz diorite (<u>see</u> Table II).

Medium-grained Bethlehem quartz diorite that occurs on the Beaver claims differs from the typical, or Skeena, variety in the following ways: (1) Quartz phenocrysts partly reach a size of 1 centimetre,

(2) Quartz in the groundmass has the open texture and, like the accompanying orthoclase, it is in semi-poikilitic grains which reach a size of 2 to 3 millimetres,

(3) Hornblende equals or exceeds biotite in amount and is partly in needles as long as 3 millimetres.

Quartz diorite occurring to the southwest of the Iona zone on the Bethlehem property is a markedly inequigranular rock which is assumed to grade into nearby porphyritic quartz diorite and resembles the rock on the Beaver claims in items 2 and 3, above. It differs from most other varieties of the Bethlehem quartz diorite in lacking quartz phenocrysts of size greater than 3 millimetres and in containing as much as 17 per cent of dark minerals, which give it a measured specific gravity as abnormally high as 2.75. The measured composition of the centres of plagioclase crystals in the rock is between An_{42} and An_{45}, and therefore not much different to that in other varieties.

Most of the Bethlehem quartz diorite of the main body on the Bethlehem property and of the smaller bodies farther north and east, respectively, is the variety termed porphyritic quartz diorite. This is a light-coloured, more or less fine-grained, inequigranular rock whose varied appearance is illustrated (Plate 1, c and d). About half the rock consists of crystals of 2 millimetre size or greater, of which a small proportion are phenocrysts whose size is 3 millimetres or greater. The rest of the rock consists of smaller crystals whose average size determines the extent to which the rock is fine grained. Phenocrysts are of the same minerals as phenocrysts in the typical medium-grained quartz diorite, which they mostly resemble in size and character. In much of the porphyritic quartz diorite however, biotite phenocrysts are plates rarely exceeding 3 millimetres and quartz phenocrysts, although partly occurring as large as 1 centimetre, may elsewhere be missing. Hornblende phenocrysts are partly squat and sieve-like and partly long needles and prisms, which by their alignment give the rock an impersistent foliation. The medium-sized crystals in the rock are mostly of plagioclase, which has the usual complex zoning and possesses cores whose composition has been measured variously as being as calcic as An_{50}, but mostly about An_{40}. The finer grained part of the rock is distinctly pink; it consists chiefly of quartz, perthitic orthoclase, and some plagioclase, and, by separating and enclosing the larger crystals, it gives a markedly porphyritic overall aspect to the rock. This finer grained part has an average grain size ranging from 1 millimetre in some rocks to one-half millimetre in others. Its texture is typically dappled, involving the wide dispersal of quartz as small grains and patches which variously are set between crystals of other minerals and are marginally intergrown with discrete but generally shapeless orthoclase (see Plate 1c and Plate Vb). In the finer grained rock the dappled texture is so fine as to appear aplitic. In the coarser grained rocks, orthoclase partly forms prominent rims on plagioclase crystals and the quartz texture is partly open and partly dappled. A proportion of the dark minerals is fine grained, and biotite especially is partly shapeless.

The measured mode of the porphyritic quartz diorite (Table 1) is not entirely representative, for in many places the rocks possess biotite and hornblende amounting together to about 10 per cent of the whole, and they may variously possess as much as 10 per cent orthoclase and 30 per cent quartz. Biotite may exceed hornblende, or vice versa, and in some places biotite is accompanied by only scarce hornblende. The measured specific gravity of specimens is variously 2.68 and 2.69 (see Table II).

A so-called <u>contact quartz diorite</u> is in fact a holocrystalline porphyry whose occurrences rarely are gradational to the Bethlehem porphyritic quartz diorite and more commonly are separate, more or less irregular partly dyke-like bodies that are emplaced in the Guichon quartz diorite, generally close to bodies of the porphyritic quartz diorite. The rock is not separately distinguished on the geological maps accompanying this report, being mainly included with the host Guichon quartz diorite and rarely shown as part of the Bethlehem quartz diorite.

The occurrences are partly very limited in outcrop and they are all located north of Highland Valley in two groups. Bodies forming a northern group are scattered in an easterly direction from south of the Krain mineralized zone, as follows:

(a) Several outcrops partly separated by the Guichon quartz diorite, extending northerly for as much as 1,000 feet on the west side of the Krain road. The northernmost outcrop is 350 feet south of the Krain camp, near the collar of drill hole No. 24, and it shows a rapid gradation eastward to the porphyritic quartz diorite (<u>see</u> map, Fig. 17). Contact quartz diorite near the surface in the drill hole, is however not gradational to the porphyritic quartz diorite, from which it is separated in the hole by a long section of the Guichon quartz diorite. The southernmost outcrops occupy an area measuring 300 feet by 200 feet, and they are the largest seen anywhere of the contact quartz diorite; they represent part of an irregular body emplaced in the Guichon quartz diorite but not separately distinguished on the map.

(b) An outcrop, without exposed contacts and not distinguished from the Guichon quartz diorite, located immediately south of the Salmo Prince access road about 1,000 feet east of mapped porphyry dykes.

(c) Farther southeast, at a location 8,000 feet west-southwest of Big Meadow Lake, a 10-foot wide northwesterly dyke dips to the southwest in the Guichon quartz diorite and is close to a mapped body of the Bethlehem quartz diorite.

Bodies forming a southern group extend southward from Bose Lake, as follows:

(a) A small outcrop 1,000 feet to the southeast of Bose Lake, shown as the Bethlehem quartz diorite.

(b) A narrowly exposed, north-trending dyke separated on the east from a larger body of the Bethlehem quartz diorite and located 1,300 feet east of Copper Lake.

(c) An outcrop 4,500 feet farther to the southeast, lying immediately east of the Outrider road and shown as the Guichon quartz diorite. Contacts are hidden and the body lies apparently between the Bethlehem and Guichon quartz diorites to the east and west, respectively.

(d) A small exposure, west of a wide porphyry dyke 2,000 feet due south of the west end of Spud Lake, of the contact quartz diorite in sharp, irregular contact to the north with the Guichon quartz diorite, from which it is not distinguished on the map. This occurrence is at a distance of about 1,000 feet from the nearest mapped body of the Bethlehem quartz diorite.

The rock is dark grey and has a strongly porphyritic inequigranular texture that may not be immediately evident, but is partly shown by conspicuous hornblende phenocrysts 1 centimetre in size. Smaller phenocrysts amounting to about half the rock consist variously of: strongly zoned plagioclase whose size is rarely as much as one-half centimetre; needle-like hornblendes which are 3 millimetres long, largely unoriented; and are perhaps the best criterions for recognition of this rock and rare biotite plates which are ragged. These phenocrysts are set amongst smaller grains, partly of the same minerals and partly of quartz and pink orthoclase, respectively. These last-mentioned minerals reach 1 or 2 millimetres in size, are partly intergrown graphically, and enclose shreds and granules of other minerals. Magnetite, apatite, and sphene are present. Some specimens of the rock contain patches of a very fine-grained groundmass, which is taken to indicate a localized, unduly rapid crystallization. The average grain size of the rock is generally between 1 and 2 millimetres and the dark mineral content is estimated at about 8 per cent. The grey appearance is largely due to rock alteration, which is commonly strong and saussuritic in nature.

BETHLEHEM GRANITE

A body comprising both granite and quartz monzonite is exposed a short distance west of the top trench of the Iona zone on the Bethlehem property and is emplaced entirely within the Bethlehem quartz diorite (see map, Fig. 7). Its exposed area measures some 1,000 feet long in a northeasterly direction and has a width of about 600 feet, but the body may extend further south beneath a drift-covered hillside. Its relations with the quartz diorite are not well exposed, but in places on the east side the two rocks occur within a few feet and retain their distinctive characters. Consequently the Bethlehem granite, as the unit is known, is likely in places to be intrusive rather than gradational into the quartz diorite, to which it is probably related in both origin and time of emplacement.

The granite and associated quartz monzonite are conspicuously pink, light-coloured, more or less porphyritic rocks which are variably fine grained, rather strongly jointed, and weather partly to shades of purple. They are cut by pink, or white, granophyric aplite dykes which cut also the adjacent Bethlehem quartz diorite. Quartz monzonite occupies the central and northern outcrops and is probably gradational to granite which occupies the eastern and southern outcrops. All the rock is similar in having a granitic-textured groundmass composed of crystals averaging between one-half and 1 millimetre in size and phenocrysts amounting to as much as 10 per cent of the rock (see Plate Ie). Quartz in the groundmass mostly appears dappled, as in the Bethlehem quartz diorite, and the groundmass of the rock is pink due to its high content of orthoclase. In order of abundance, plagioclase, quartz, and biotite make phenocrysts of size between 2 and 3 millimetres, and are accompanied by equally large, sieve-like hornblende phenocrysts only in the northern outcrops which are of quartz monzonite. Compared to the granite, quartz monzonite shows a relative increase in the amount of plagioclase present as chalky-white phenocrysts and smaller grains. In both rocks, the plagioclase phenocrysts have a complex zoning and an optically determined composition, which is basic andesine, that make them similar to phenocrysts in the Bethlehem quartz diorite; other plagioclase is more nearly albite in composition. Quartz phenocrysts of both rocks are similar to those of the quartz diorite in being composed of interlocking small grains. Biotite, which forms plates and shreds in the groundmass as well as rare platy phenocrysts, is commonly the only dark mineral present apart from magnetite. Orthoclase is perthitic and mostly forms shapeless, moderate sized grains which, as seen under the microscope, variously are moulded to plagioclase and biotite, mutually interfere with quartz, and locally enclose smaller quartz grains. In the granite, orthoclase partly combines with quartz to form radial, graphic or granophyric intergrowths several millimetres in size which occupy a considerable volume of rock, especially that of the southernmost outcrops. This strongly granophyric rock contains, in addition, small cavities lined with projecting quartz crystals, epidote, and rusted chlorite, or mica.

The model composition of quartz monzonite from the central outcrops is given in Table I; that of granite is not given but would differ mainly by showing a lower ratio of plagioclase to orthoclase.

BETHSAIDA GRANODIORITE

This incompletely mapped unit forms a stock which underlies the Bethsaida property and extends southward and eastward for a further distance of more than 10 miles. The stock is surrounded largely, if not entirely, by the Bethlehem quartz diorite and has poorly exposed contacts in the present area. No exposures of it are known to the north of the O.K. road, which probably is close to its northern limit. The approximate western contact of the stock is mapped near the O.K. mine (see Fig. 3) from where it goes southwestward beyond the mapped area for 1 1/2 miles, before turning southward to the west end of Pimainus Lake and continuing farther to the south-southeast. The eastern contact is precisely located only near the Lornex deposit, whence it probably extends southeastward to the headwaters of Skuhun Creek. On Gnawed Mountain a mapped body of porphyritic granodiorite is less than 1,000 feet wide, is heavily dissected by porphyry and breccia intrusions, and is thought to be a connected, easterly prong of the Bethsaida stock, which as a whole is thereby indicated to be intrusive into, and somewhat younger than, the surrounding Bethlehem quartz diorite.

There are few places where the stock is seen in actual contact with the Bethlehem quartz diorite. The western contact is everywhere obscured by overburden and here the two rocks outcrop locally within 200 feet of one another without appreciable change in the grain size of either. The eastern contact as seen in Lornex drillholes is partly a faulted one and partly one at which the granodiorite grades marginally to porphyry in contact with the quartz diorite. This porphyry, named the Bethsaida porphyry, is seen in drill hole No. 57 and in a trench at approximately 36 South on the Lornex base line. At Gnawed Mountain the Bethsaida porphyry occurs as a marginal phase of the porphyritic granodiorite in outcrops near the summit but is absent at some other places on the contact; for example, north of the Minex cabin where a dyke of unchilled porphyritic granodiorite cuts the quartz diorite, and likewise in the Highmont adit. The difficulty experienced at Gnawed Mountain in distinguishing systematically the Bethsaida porphyry from a later breccia-forming porphyry has necessitated its inclusion with the latter as unit No. 5 on the map (Fig. 3).

In the present area the Bethsaida granodiorite and porphyritic granodiorite form light-coloured outcrops which mostly show some degree of fracturing and alteration and are neither as massive nor as fresh as many seen farther south. In places the rocks are cut by pink aplite veins which are mostly less than a few inches wide and which on Gnawed Mountain partly contain large quartz phenocrysts resembling those in the host granodiorite. The granodiorite differs in its field appearance from the medium- grained Skeena variety of the Bethlehem quartz diorite principally as follows:

1. It is coarser grained, having phenocrysts of size between one-half and 1 centimetre, with intermediate-sized crystals and a groundmass of crystals averaging about 1 millimetre in size. The phenocrysts are of quartz, biotite, and plagioclase and are conspicuously larger than those in the Skeena rock (<u>see</u> Plate 11a).

2. It is somewhat lighter coloured and contains lesser amounts of dark minerals, which commonly form between 5 and 7 per cent of the rock.
3. It is largely free of hornblende, not only as phenocrysts but also as smaller crystals, and the groundmass therefore lacks the fine speckling seen in the Skeena rock.
4. Biotite phenocrysts form thicker books, frequently measuring as much in thickness as in width.

The mode of the granodiorite given in Table 1 is not entirely representative, being unduly low in quartz and correspondingly high in the feldspars, whose true amounts are probably nearly as follows: Quartz, 25 per cent; plagioclase, 60 per cent; orthoclase, 8 per cent. The determined specific gravity (Table II) is of a specimen from outside the area that contains minor amounts of hornblende; it is 2.67 and less than those of all the previously described rocks. The analyzed chemical composition and the calculated normative composition of the Bethsaida granodiorite as shown in Table III.

Under the microscope the granodiorite exhibits an hypidiomorphic granular texture which is porphyritic, inequigranular, and much like that of the Skeena rock. Phenocrysts occupy much the same volume in both rocks but they reach larger sizes in the granodiorite. Quartz phenocrysts comprise several aggregated, interlocking grains, and possess partly anhedral outlines which accommodate to the shape of neighbouring better-formed plagioclase crystals (Plate Vc). They may deeply enclose small crystals of feldspar, magnetite, and other minerals. Biotite phenocrysts similarly enclose other minerals and, although relatively well shaped, they too have partly anhedral outlines. Plagioclase phenocrysts are broad and well shaped and they show a very complex oscillatory zoning which ceases at a wide marginal zone of sodic composition. The optically determined composition of the centre of a phenocryst is An_{35}; in view of the zoning present and judging from the analyzed chemical composition of the rock the average plagioclase composition in the granodiorite is probably that of an oligoclase close to An_{30}.

The same minerals that form phenocrysts occur also in smaller sizes together with orthoclase and accessory minerals, which include magnetite, sphene, apatite, and zircon. Only a small amount of biotite occurs as small crystals, which are generally poorly shaped and partly enclose minute grains of quartz, plagioclase, and other minerals to form sieve-like crystals. Whatever their size, all plagioclase crystals in the rock are zoned in like manner to the phenocrysts. Orthoclase, which is pink in hand specimens, forms poorly shaped grains of size as much as 2 millimetres and poikilitic masses which are continuous spatially for 4 millimetres and optically for greater distances (<u>see</u> Plate Vc). Although partly structureless, orthoclase exhibits, in separate specimens of rock, several kinds of internal structure which include weakly or strongly developed vein- and patch-perthite and microcline twinning. It encloses occasional patches of myrmekite, which is a micrographic intergrowth of plagioclase and quartz that is common in granitic rocks and whose origin is disputed (Deer, Howie and Zussman, 1963, p. 76). Quartz in granular aggregates is noticeably interstitial to plagioclase crystals, and it thus forms a texture which may be described as a discontinuous variety of the open texture illustrated by Figure 6b. Its granular, interlocking habit is probably the result of its inversion to a different structural state, either during cooling or possibly through later metamorphism or pervasive hydrothermal alteration. Accessory minerals in the rock include magnetite, sphene, apatite, and zircon, of which magnetite is in grains of size 0.2 millimetre that partly coalesce to form shapeless masses as large as 1 millimetre. Sphene is generally in shapeless masses rarely as much as 2 millimetres in size which are evident in hand specimen and commonly enclose grains of magnetite, quartz, and other minerals. Apatite forms relatively large, well-shaped prisms as much as 1 millimetre in length.

In contrast to the above-described rock in the mapped northern portion of the Bethsaida stock, granodiorite farther south contains hornblende as prominent scattered, sieve-like phenocrysts and needle-like smaller crystals and it also contains correspondingly less biotite, which remains the predominant dark mineral in the rock. Under the microscope the southern Bethsaida granodiorite shows a strongly poikilitic texture of both quartz and orthoclase, or microperthite.

Porphyritic granodiorite differs from the described granodiorite chiefly in the dappled texture and smaller grain size of its groundmass (<u>see</u> Plate Vd). Phenocrysts of varying size make up about half the rock by volume and they resemble the larger crystals in the granodiorite, but mostly they have sharper outlines than the latter. Quartz phenocrysts may be as large as 1 centimetre and each is optically uniform, unlike those of the granodiorite; biotite phenocrysts are book- or concertina-shaped and they rarely exceed one-half centimetre in width. Hornblende is rarely seen, and then only as small crystals. Accessory minerals are those usually found in the batholithic rocks and they include magnetite, apatite, and sphene. The dappled groundmass is composed partly of the same minerals as the phenocrysts; namely, quartz, plagioclase, and biotite. It also contains orthoclase, which shows pink in outcrop and has a tendency to form rims on plagioclase crystals as well as to occur as small, discrete grains. Quartz is locally moulded on other minerals. The groundmass has an average grain size of the order of 0.2 millimetre and texturally it resembles that of the Bethlehem porphyritic quartz diorite (see Fig. 6d).

The Bethsaida porphyry differs in appearance from the porphyritic granodiorite chiefly in possessing a fine-grained aplitic groundmass, which is white or faintly pink and in which the phenocrysts of quartz, plagioclase feldspar, rarely potash feldspar, and bookish biotite exhibit a considerable range in size and stand out sharply.

Unique occurrences of sedimentary rock lie within the Bethsaida granodiorite in the easternmost trenches on the Bethsaida property. Compact grey quartzite, the like of which is unknown elsewhere in the vicinity of the Guichon batholith, is partly well banded and forms two apparently separate bodies 430 feet apart in an east-northeasterly direction in trenches A and C, which are on the M.D. No. 5 claim and F.C. No. 1 fractional claim, respectively (see map, Fig. 30). Both bodies are some 5 feet wide as exposed, with walls, banding, and joints that all strike east-northeasterly and dip southerly. Banding in the eastern body makes a tight isoclinal arch whose axial plane dips southward at 50 degrees, and the walls of the body are sheared and dip southward at about 60 degrees. Banding in the western body is poorly defined and the north wall of this body has a low southerly dip. Both bodies are relatively well mineralized and they partly contain an estimated 1 per cent copper as chalcopyrite which is disseminated finely throughout and which to some extent follows banding, or bedding (see Plate IIb). Under the microscope, the rock is mostly a granular, interlocking aggregate of quartz grains whose average size is approximately 0.2 millimetre and which are strongly clouded although margined by clear quartz. Between one-tenth and one-fifth of the rock is sericite, occurring as fine laths and blades which lie disoriented with respect to the banding but which are partly concentrated selectively in certain bands. Minerals present in smaller amounts include calcite, sphene, chalcopyrite, and probably kaolinite.

The source and manner of emplacement of the quartzite bodies, and why they apparently lie on strike with each other, are intriguing and unsolved problems.

PORPHYRIES

These minor intrusions of pre-mineral age may be emplaced in any of the above described rocks but are mostly in the Guichon and Bethlehem quartz diorites. They include countless porphyry dykes in a swarm that extends northward through the central part of the mapped area and is separated by a distance of about 2 miles from a few dykes of more or less different porphyries near Foot Lake to the east. Several fairly large, irregularly shaped porphyry bodies are connected to dykes in the swarm and occur roughly at the same locations as does breccia (see Fig. 5).

The dyke swarm is mapped for a length of 10 miles and is roughly from 3 to 5 miles wide (see Fig. 5). Its western limit is partly hidden by Tertiary volcanic rocks on Forge Mountain and curves southwestward through the Bethsaida showings. Its eastern limit skirts the eastern edge of volcanic rocks on Bose Hill and extends due south past Spud Lake to the eastern slope of Gnawed Mountain. Dykes are spaced across the swarm mainly at intervals ranging from 300 feet to 1,000 feet and they are particularly abundant on the Bethlehem property and other properties near the centre of the swarm. They mostly strike more or less parallel to the swarm and their average strike varies from place to place as shown (see Fig. 5). They locally follow several contrasted directions as, for example, near the Transvaal and Krain properties. For descriptive purposes a distinction is made between dykes, which are steep and tend to persist along strike, and sheets, which are offshoots of the larger intrusions and possess rapidly varying attitudes, partly low to moderate angles of dip, and a marked tendency to pinch out rapidly.

The dykes have dips mostly within 20 degrees of vertical and they are rarely more than 100 feet wide and mostly about 40 feet wide. Since their edges are chilled and the adjacent rock is commonly devoid of shearing or alteration, they were emplaced in cold rock and did not, in general, follow faults. While many dykes probably extend only for short distances, numerous others are more persistent and have been variously mapped and correlated for distances of several hundred feet. At Spud Lake a wide dyke persists for certainly as much as 1 mile and probably much farther, since a dyke shown on strike 6 miles to the south is virtually identical. Joints in the dykes are mostly wide-spaced and partly in steep sets, of which generally one is roughly parallel to the dyke and another crosses it. In narrow porphyry sheets closely spaced joints may divide the rock into irregular slabs which are more or less parallel to the sheet (see Plate VIj). Except for one or two dykes replete with xenoliths, the porphyry bodies are generally free of inclusions or debris of the country rocks and they are likewise mainly free of later aplite veins, although the latter do occur sporadically in the larger porphyry bodies. A foliation due to crystal alignment is locally evident in the dykes and other bodies and, since its direction is highly variable, it is a poor guide to the attitude of the containing body. The dykes and other bodies have little or no topographic expression and cannot therefore be located readily by the study of air photographs or groundforms. Microscopic examination has shown that most of the Highland Valley porphyries are dacites or rhyodacites which, since their precise plagioclase compositions are mostly unknown, are indistinguishable and accordingly are all termed dacites in this report. A few porphyries are found to be quartz latites and rhyolites,* and all are light-coloured rocks which have small amounts of dark minerals.

An attempt is made to subdivide the porphyries into types on the basis of their differing field appearances, although not as successfully as more detailed work would in places probably allow. On the map (Fig. 3), several types are included together in unit No. 5 as the breccia-forming quartz porphyries. Remaining porphyries are all placed in unit No. 7 and they include types distinguished by letters and subsequently described in the text. Of these types, Type C is belatedly recognized as probably equivalent to the Krain porphyry of Unit No. 5, with which it is therefore described. In the vicinity of the Trojan mine, dykes and sheets variously of Types C and D were mapped together under the field name of brown porphyry, whose composite nature was not then realized.

Breccia-forming Quartz Porphyries

Porphyries of Map Unit No. 5 include four types, each of separate occurrence but together mainly constituting a zone, nowhere more than 1 mile wide, that extends more or less continuously for the length of the dyke swarm, from Gnawed Mountain in the south to the Krain property in the north (see map, Fig. 3). From Gnawed Mountain an additional zone of porphyry intrusion extends west-northwestward along the prong of Bethsaida granodiorite

* Dacite and rhyodacite are the respective fine-grained equivalents of quartz diorite and granodiorite, and quartz latite and rhyolite are the respective equivalents of quartz monzonite and granite.

for as much as 2 miles, and other scattered occurrences probably of breccia-forming porphyry lie farther north and west on the Alwin, Bethsaida, and Valley Copper properties.

In addition to dykes each type forms one or more larger intrusions which are of irregular shape and commonly multiply-sheeted. All are dacites or rhyodacites in composition, except for a variety at the Trojan mine which is rhyolite. They are described in the order of best to least known, starting with the type occurring at the Bethlehem mine and ending with that at Gnawed Mountain.

$\underline{P_3}$: The breccia-forming porphyry on the Bethlehem property is known by its original designation of P_3. It was apparently the first porphyry to be emplaced on the property and it forms a relatively large intrusion, which is dyke-like to north and south, and two separate groups of dykes which lie farther east and west, respectively (*see* Fig. 8).

The large intrusion spreads at surface across an irregular area measuring about 6,000 feet in a northerly direction and as much as 2,000 feet from east to west (*see* Figs. 3 and 9). An underlying dyke, or dykes, reaches the surface to the north and south (D-D on Fig. 9) and is considered to have fed the intrusion, whose form is that of a branching, multiply-sheeted body. The sheets branch upwards mainly to the east but at the Jersey orebody they appear to form a cup-shaped mass whose western lip fails to reach the surface and whose shape was probably dictated by a pre-existing basin in the upper surface of the Bethlehem quartz diorite (*see* Figs. 8 and 10). The south end of the intrusion lies west of the Iona orebody and consists of a dyke about 40 feet wide that possesses a steep dip to the west and a chilled edge against the adjacent Bethlehem granite. Towards its north end, which lies north of the Jersey orebody on the south part of the S.J. No. 50 surveyed mineral claim, the intrusion consists of two or more north-trending dykes, of which one is about 70 feet wide, that are mainly steep although locally one of the dykes possesses a chilled edge which dips eastward at 35 degrees. Farther north these dykes probably converge to form a single dyke that is apparently intersected by rotary-drill holes No. CR 74 and CR 80.

The sheets comprising the intrusion are of many sizes and they range in width from less than an inch to more than 100 feet. Against the quartz diorites they exhibit sharply defined edges which in places are chilled; against breccia their contacts are partly abrupt and lack apparent chill, or they are more or less gradational from brecciated P_3, as described in the section dealing with breccia. At the Iona orebody and other large breccia zones, the mapping is partly generalized and fails to show the interfingering of breccia, P_3, and older rocks. In these zones, fragments and isolated larger bodies of P_3 must represent disrupted sheets in breccia, whose original distribution is impossible to reconstruct.

The flanking groups of P_3 dykes are poorly exposed. East of the Creek showing mainly on the S.J. No. 114 fractional claim, the eastern group comprises two or more north-to northeasterly-trending dykes that are exposed mainly in a long trench, and of which one is probably intersected by rotary-drill hole No. CR 160 (<u>see</u> Fig. 3). About 1 mile farther northwest, the western group of dykes is marked by a series of exposures extending northward between the South Simons showings and the Huestis orebody (<u>see</u> Fig. 8) and including, to the south on the S.J. No. 34 claim, several dykes possibly of northeast strike. Successively farther north, drill hole No. CR 157 probably intersects a P_3 dyke, and two small outcrops on Jersey Creek at 4,740 feet elevation consist of P_3 whose texture indicates the presence of a sizeable body of this rock. Narrow lenses of breccia occurring nearby in the 4600 level adit likewise suggest that more of the breccia-forming porphyry should exist in the vicinity.

Except for very fine-grained, chilled edges and stringer consisting of a felsitic or flinty rock, which is variously pale-grey, pink, or deep red and contains only a few small phenocrysts, P_3 chiefly includes three textural varieties, two being aphanitic and the other phaneric*, which are gradational in both appearance and occurrence. The varieties possess a common assemblage of phenocrysts mostly exceeding 1 millimetre in size and including plagioclase abundantly, quartz, hornblende, and rarely biotite. Plagioclase forms well-shaped, tabular phenocrysts of maximum length 6 millimetres which are white where fresh and show striations due to multiple twinning. They also commonly show concentric zones due to compositional zoning. Hornblende phenocrysts are well-shaped in the aphanitic varieties and fuzzy in the phaneric variety partly because of their stronger alteration in the latter rock. The larger are squat, dark-green prisms that are partly sieve-like and rarely 1 centimetre long, and the smaller are needle-shaped. Quartz phenocrysts seldom measure as much as 3 millimetres, appear glassy and contain minute feldspathic inclusions, and possess various sub-angular, rounded, and deeply embayed shapes that are partly kidney-like and then provide a useful, but not infallible, guide to the recognition of P_3 (see Fig. 6d and Plate V, e and f). Biotite phenocrysts are uncommon and form plates rarely 3 millimetres in size. In all three main varieties of P_3, phenocrysts account

*Aphanitic and phaneric are terms describing the degree of crystallinity, the former indicating a groundmass too fine-grained for crystals to be seen under a pocket lens and the latter a groundmass in which most of the crystals are visible.

for about 45 per cent of the volume and the rest is second-generation crystals and groundmass material. Second-generation crystals which comprise above-mentioned mineral consist variously of components and orthoclase. They range in size from one-quarter to one-half millimetre and are conspicuous only in the aphanitic rocks.

The aphanitic variety typical of the dykes is a light-coloured porphyry with a pinkish weathered crust. On a fresh surface it shows phenocrysts, second-generation crystals, and speck-like smaller crystals (<u>see</u> Plate II d), which are all set in a white to slightly pink or greenish groundmass that becomes flintier towards the edges of the dykes. Narrow, pure white mantles surrounding the quartz phenocrysts are formed of quartz-rich groundmass material. Under the microscope, the groundmass is mostly resolvable as an irregular mosaic mainly of quartz and sodic plagioclase with lesser amounts of orthoclase (<u>see</u> Plate Ve). Although mostly very fine-grained, its texture varies in blotchy fashion and near the centres of the dykes it may include crudely poikilitic patches, rarely as large as 1 millimetre and variously of quartz and plagioclase, which appear to have formed partly by enlargement of second-generation crystals. Quartz phenocrysts are optically uniform and not inverted to aggregates, and plagioclase crystals of all sizes show an intense oscillatory zoning and their composition probably ranges through andesine. Accessory minerals include apatite, magnetite, sphene, and chlorite, which is probably derived by alteration of biotite that is otherwise absent.

A chemical analysis of this aphanitic variety of P_3, collected from the northern exposure of the feeder dyke, is given in Table III together with the calculated normative composition of the rock, and is discussed in a later section of the report.

The second aphanitic variety of P_3 is transitional to phaneric porphyry, for example, in Bethlehem drill hole No. B16 at 471 feet, and it differs from the first-described variety mainly in an abundance of second-generation crystals, which are chiefly quartz and which amount perhaps to 25 per cent of the rock. These rounded and crowded small crystals give the variety a distinctive "fish-egg" appearance. The groundmass is fine grained, as in the previous rock, and is a more or less uniform, quartzofeldspathic mosaic without blotchiness and quartz mantles. The final crystallization of the rock was rapid, as evidenced by the fine-grained groundmass, and it occurred within a jacket of phaneric P_3; presumably therefore it resulted, not from cooling, but from an escape of volatiles from certain parts of the P_3 sheets before their final consolidation.

The phaneric variety is commonly called aplitic P_3 and is a light grey porphyry which superficially resembles the porphyritic Bethlehem quartz diorite (see Plate IIe) but which, on closer examination, reveals a fine-grained, partly pinkish groundmass mainly of quartz and feldspars, in which a part of the quartz shows as separate, minute grains resembling pin-pricks and characteristic of aplitic texture (see Fig. 6d).

The modal analysis and specific gravity of aplitic P_3 are given in Tables I and II, respectively. Phenocrysts in this rock range upwards in size from one-half millimetre and they amount to 46 per cent by volume of the analyzed specimen. They are similar to those of the aphanitic P_3, except their outlines are fretted due to mutual interference with groundmass material, and they lack white mantles around the quartz phenocrysts. Together with smaller, second-generation crystals which are relatively few in number, phenocrysts of plagioclase and hornblende commonly exhibit a perceptible degree of alignment which has not been generally mapped. Optical measurement of the compositional range in a zoned plagioclase phenocryst gave values covering nearly the whole andesine range from An_{50} at the centre to An_{34} near the margin of the crystal. In all specimens examined under the microscope, hornblende and biotite are altered almost entirely to pseudomorphs composed variously of chlorite, epidote, calcite, and quartz. Biotite occurred only as a second-generation, and smaller crystals of the accessory minerals magnetite and sphene form grains or aggregates of size as much as one-half millimetre, and apatite forms minute prisms. Viewed microscopically, the groundmass is mostly a rather uniform, aplitic mosaic with quartz and plagioclase possessing an average grain size which ranges, in various specimens, between 0.1 millimetre and 0.2 millimetre. In stained thin section, orthoclase shows three habits: (1) discontinuous rims on plagioclase phenocrysts, (2) poikilitic masses continuous for as much as one-half millimetre in the groundmass and enclosing numerous quartz and plagioclase grains, (3) anhedral grains as part of the aplitic mosaic. In addition to accessory minerals and small amounts of altered hornblende and biotite, minerals in the groundmass of the analyzed specimen (Table 1) are in the following proportions: Quartz, 54 per cent; plagioclase, 33 per cent; orthoclase, 13 per cent. Local graphic intergrowths of quartz and orthoclase occur in the groundmass of some specimens, and there may be a tendency of quartz to occur poikilitically moulded on second-generation quartz crystals.

<u>Trojan Rhyolite</u>: This type of breccia-forming quartz porphyry is recognized only at the Trojan breccia pipe, where it forms a dyke-like intrusive body extending northward for a known distance of 1,200 feet in the Guichon quartz diorite and breccia. The body possesses numerous minor

offshoots and, especially in its northern part, it consists partly of alternating sheets of rhyolite porphyry and breccia. This breccia contains a varying abundance of rhyolite porphyry fragments and may be termed rhyolite breccia, in distinction to breccia without such fragments that is equally common in the pipe. In places, the continuity of the porphyry body becomes apparent only when the two kinds of breccia are distinguished, as was done by core logging but generally not by surface or underground mapping. Consequently, sections based on drill hole information (Fig. 16) give a better idea of the form of the rhyolite porphyry body than do the geological maps (Figs. 14 and 17). The body is best known at depth, and may in fact scarcely reach the bedrock surface, and the trend of this adjacent porphyry body is therefore shown on the surface geological maps by upward projection from an elevation 500 feet below that of the shaft collar (Figs. 3 and 14).

The southern part of the body is apparently a steep porphyry spine whose width exceeds 200 feet in drill hole No. S-24 (<u>see</u> Fig. 16, section B-B'), and which is believed to plunge northwards to depths greater than explored. The porphyry spine is adjoined in the drill hole by rhyolitic breccia, more of which occurs both locally in the spine and associated partly with narrow intersections of rhyolite porphyry elsewhere in the southern part of the breccia pipe. The northern part of the body consists of a main branch extending through the Trojan west zone and lesser branches that are intersected by drill holes farther east in the breccia pipe. The form and continuity of the lesser branches are unknown. The main branch is probably connected tenuously to the porphyry spine and it has the form roughly of a vertical dish, concave on its east side and with a maximum horizontal width in places exceeding 200 feet, of which only a small proportion consists of solid rhyolite porphyry and the remainder occurs as breccia. The main branch divides towards the north into several arms or leaves, which are thought to terminate more or less as shown*. In drill core the northern part of the body comprises repeated porphyry sections, each a few feet to several tens of feet wide and partly strongly brecciated, that are interspersed with breccia which is partly rhyolitic. Although not shown on the level map (Fig. 17), two or three 10- to 20-feet wide porphyry sheets were identified underground at the west zone and they probably correlate in part with drill intersections to suggest a north-striking, west-dipping porphyry sheet of restricted dimensions. While many of the porphyry contacts seen in drill core are sheared and therefore useless for interpretation, others show evidence that emplacement of the rhyolite porphyry was preceded, as well as followed or accompanied, by brecciation. Thus in places the porphyry remains unbrecciated at its contacts with the brecciated quartz diorite, and elsewhere it consists partly of intrusive stringers which are seen to cut breccia. The rhyolite porphyry is apparently later emplaced than a so-called brown porphyry, which is seen rarely as fragments in the rhyolite porphyry and which occurs mainly as dykes in the Guichon quartz diorite and as large and small masses in the breccia pipe. The brown porphyry consists partly of Type C porphyry, which is probably equivalent to the Krain breccia-forming quartz porphyry, and may have produced a phase of brecciation at the Trojan breccia pipe preceding that caused by the Trojan rhyolite porphyry.

The only known outcrops of rhyolite porphyry lie northeast of the Trojan shaft, where two masses each about 30 feet wide are exposed.

* Information obtained from an examination of the 1964 and 1965 drill holes is omitted from the accompanying geological maps and sections; it does not greatly change the described geology of the Trojan breccia pipe.

The rock is altered, felsitic, greyish-green in colour, and possesses an irregular platy jointing which roughly follows a well-developed, locally contorted flow layering that is expressed by a colour banding (Plate IIf). In the exposure nearest the shaft, the banding possesses a moderately steep dip to the northeast and it partly adopts fold-like attitudes with easterly plunges measuring 45 degrees. In the other exposure, banding possesses a northeasterly strike and a steep dip. In these outcrops the only visible indication that the rock is porphyritic is the occurrence of small pits in its surface due to the weathering of altered feldspar and of sulphide grains. Rock similar to this comprises many of the porphyry sheets and breccia fragments in the northern part of the rhyolite body and is seen from specimens of drill core to contain, almost to one-third of its volume, streaks and lenses of chalcedonic appearance lying crudely parallel to one another. Viewed on a smoothly sawn surface of the rock, the chalcedonic streaks appear to represent amygdular masses in vesicles of contorted or irregular shapes. They lie within a fine-grained, flow-banded groundmass containing a few altered, tabular feldspar crystals and rare quartz crystals, which are small, rounded, and inconspicuous. Under the microscope the rock is streaky, heterogeneous, partly cryptocrystalline, and appears to consist mainly of quartz, chlorite, and argillic, or sericitic material together with calcite that pseudomorphically replaces 1- to 2-millimetre long phenocrysts, once probably orthoclase. Rhyolite porphyry of the southern part of the body is seen in drill hole No. 24 to be a pale grey, greenish, or pinkish, generally aphanitic and flow-textured rock possessing phenocrysts of quartz and others of elongate hornblende and well-altered, tabular feldspar which together compose about one-fifth of the rock. The porphyry is not entirely uniform and it shows in places a patchy, streaky, or mottled appearance, and partly a brecciated aspect. Under the microscope feldspar phenocrysts are all identified as orthoclase, which appears faintly perthitic and is partly replaced variously by quartz, sericite, minor chlorite, and locally calcite (Plate Vg). Quartz phenocrysts are rarely larger than one-half millimetre, are optically homogeneous, and variously sub-rounded and angular. Phenocrysts of ferromagnesian minerals have been entirely replaced by chlorite and minor sericite and epidote; they were probably mainly hornblende, of which crystal outlines remain. Other crystals present are variously of apatite and monazite, both not exceeding one-third millimetre in size, magnetite in small rare grains, and sphene. The groundmass of the rock ranges from cryptocrystalline to finely crystalline and it encloses very minute crystals, similar in composition to the phenocrysts, and irregularly drawn-out vesicles containing radially grown chlorite and also sericite and orthoclase. As shown by selective staining, the groundmass contains a large amount of orthoclase, possibly as much as 50 per cent, which is well disseminated and is partly in fine, mosaic-textured lenses with quartz. By partial alteration of orthoclase, sericite has become an abundant component of the groundmass. Although its fineness of grain prohibits an accurate modal analysis of the rhyolite porphyry, its original composition is estimated approximately as follows: Phenocrysts, 19 per cent (quartz, 1 per cent; orthoclase, 15 per cent; hornblende (and biotite?), 3 per cent); vesicles, 3 per cent (mostly chlorite): groundmass, 78 per cent (about half of which is orthoclase). Fragments of similar porphyry are common in the southern part of the breccia pipe, but they partly show a more pronounced pink colour, a greater content of orthoclase in the groundmass, which contains an estimated 60 per cent of this mineral, and a much greater degree of replacement of orthoclase phenocrysts by quartz.

Krain Porphyry: Porphyry dykes and sheets occurring in the vicinity of the Krain deposit are mostly of a type named the Krain porphyry, which is emplaced mainly in the Guichon quartz diorite and locally in the Bethlehem quartz diorite and is considered to be breccia-forming on the evidence of an association with breccia at a single locality. On Figure 3 the Krain porphyry is shown as confined to an area covered by the accompanying map of part of the Krain property (Fig. 18), with porphyries probably equivalent to it occurring variously farther south and southwest and lettered C. These Type C porphyries, which are described later in this section of the report, include much of the brown porphyry at the Trojan mine.

The Krain porphyry extends northward as a series of partly connected and branching dykes and sheets for a distance of as much as 3,600 feet, its further extension being hidden to the north by overlying Tertiary strata (see Figs. 3 and 18). Its southern occurrences consist of as many as five dykes, each partly as wide as 100 feet, which strike predominantly north-northwest and mostly dip westward at moderate to steep angles. Branches of these dykes strike slightly east of north and possess westerly dips. A probable northern extension of one of these dykes is exposed in a small outcrop to the west of the Transvaal-Krain road.

Central occurrences lie about 800 feet farther north and they consist of a similar north-northwest trending porphyry dyke which splits into three branches at a point where it is locally in contact with a breccia containing fragments of the selfsame porphyry. The western and middle branches are traced northward for distances of as much as 1,200 feet. The eastern branch trends eastward and is apparently crossed by narrow, north-northwesterly dykes of similar porphyry, one of which is further exposed just north of the camp (see Fig. 19). Farther northeast and partly containing the Krain mineral deposit are northern occurrences of the Krain porphyry, which here forms bodies that are chiefly known from drill holes (see Figs. 19 and 20) and were intermittently exposed in trenches that are now largely caved. A dyke-like eastern body probably dips westward partly at moderate angles and may be a northern continuation of the eastern branch of the central occurrences. A much larger western body splits, frays, and diminishes in size, and becomes more northerly in trend toward the surface, and in depth is partly a northwesterly trending, roughly tabular dyke or sheet that dips predominantly southwestward at about 60 degrees and is as much as 300 feet in true width. The tabular part of this body extends northwestward between holes No. 3 (1965) and No. 3 (1956) for a distance of about 500 feet, beyond which the continuity and shape of the body are uncertain. Similar porphyry which occurs in drill holes farther to the north and northwest may represent partly this body and partly other bodies, such as the middle branch of the dyke mentioned above.

In its appearance (see Plate 11g), general composition, and range of texture the Krain porphyry compares closely with the previously described P_3 porphyry. Features which it shares with the P_3 include the following:

(1) Dacitic composition.

(2) Aphanitic and aplitic varieties which are partly gradational.

(3) Pink aplite veins, rarely 1 inch wide, in the aplitic variety.

(4) Mainly similar phenocrysts, which are: quartz as partly strongly embayed, or kidney-shaped, phenocrysts containing pale inclusions; plagioclase with well-developed oscillatory zoning; well-shaped hornblende that is partly sieve-like and partly elongate; and biotite in plates and also in thick books.

(5) A mainly similar groundmass which, although ranging in grain size from microcrystalline (aphanitic) to phaneric (aplitic), is a mosaic and locally an intergrowth of quartz with mostly plagioclase and some orthoclase and accompanying minerals.

(6) Small, second generation phenocrysts, including abundant ones of quartz and plagioclase which commonly give a crowded appearance to the rock.

It differs from the P_3 porphyry chiefly in possessing mainly fewer and less conspicuous quartz phenocrysts, more abundant biotite, and an aplitic texture which is less of a simple mosaic and more an intergrowth of groundmass crystals.

Rock alteration and weathering account partly for the wide range in colour shown by the Krain porphyry on fractured surfaces and in drill cores, which are variously mainly white, pink, grey, green, and less commonly, brown and red. The least altered rock weathers to a light grey or buff colour and its weathered surface is pitted minutely by slot-like cavities once occupied by tabular plagioclase and other phenocrysts. Outcrops are traversed by joints which divide the rock into blocks and slabs. Dykes and sheets are margined by narrow selvages of dark-coloured or pink, densely aphanitic chilled porphyry which commonly lacks conspicuous quartz phenocrysts and which grades rapidly to the usual aphanitic variety of porphyry. One such selvage at the west side of the middle dyke, north of the breccia locality, is found under the microscope to contain numerous broken crystals mainly of plagioclase, which shows it to be autobrecciated and provides confirmation of the breccia-forming nature of this porphyry. A chemical analysis of the rock of this selvage is given in Table 111, E.

Aphanitic porphyry and aplitic porphyry have similar phenocrysts which, including second generation phenocrysts, amount to about 60 per cent of the volume of each rock. Quartz phenocrysts vary in abundance, and also in shape from square to irregular, and they rarely exceed a size of 1 millimetre. Those in the aphanitic porphyry are commonly each enclosed in a narrow white mantle of siliceous groundmass material. Plagioclase phenocrysts are rarely as much as one-half centimetre long and they may be replaced partly by epidote or rendered dark by incipient argillic and sericitic alteration. Together with hornblende and biotite crystals, they may be aligned to give the rock a distinct foliation which, in the dykes, is generally parallel to the strike of the porphyry body. Hornblende and biotite together amount to as much as 10 per cent by volume of the rock, mainly as phenocrysts but partly in the groundmass. They are widely chloritized and otherwise altered, although in places the amount of biotite is apparently increased by hydrothermal alteration. The needle-like shape of many hornblendes helps in recognition of the rock. Hornblende phenocrysts achieve a size of 4 millimetres, whereas the largest biotites are rarely more than 2 millimetres across and may be equally as thick. Accessory minerals in the porphyry include apatite, sphene, and magnetite, the latter making occasional grains, or aggregates of grains, which measure partly greater than 1 millimetre and therefore appear to be phenocrysts.

The two varieties of porphyry are gradational in the field and they differ only in the texture of their respective groundmass, which in the aphanitic variety is seen under the microscope mainly as a turbid, microcrystalline mosaic, chiefly composed of quartz and feldspar. The groundmass in both the aphanitic and aplitic varieties includes small irregular areas of coarser grained quartz, either alone or with orthoclase and plagioclase respectively as granophyric and myrmekitic intergrowths.

which led to this rock being given the field name of granophyric porphyry. In the aplitic variety the groundmass is crudely aplitic and it generally consists largely of quartz and plagioclase grains averaging 0.2 millimetre in size, which are accompanied by intergranular orthoclase. The orthoclase content is hard to measure even in stained thin sections, and is of the order of 8 per cent by volume of some specimens of the rock, and less in others. The texture of the aplitic Krain porphyry is partly apparent in the photomicrograph (Plate V, h).

The measured specific gravity of a specimen of rather fine-grained aplitic Krain porphyry obtained from the dyke-like eastern body is 2.62.

Dykes lettered C on the map (Fig. 3) consist of porphyries that are probably equivalent to the Krain porphyry and they mostly occur in a northern group lying immediately south and southeast of the Krain area and in a southern group at the Trojan mine. Dykes of the northern group occur as far west as the Transvaal adit, are emplaced in the Guichon quartz diorite, and possess strikes which are variously between north and west-northwest. They consist of porphyry which closely resembles the Krain porphyry and appears mainly pinkish grey or red on freshly broken surfaces. Some dykes possess well-defined, mostly small quartz phenocrysts, while others contain quartz which is visible only as irregular groundmass patches. Most specimens collected from these dykes are phaneric rather than aphanitic, and many show appreciable amounts of alteration.

Dykes of the southern group at the Trojan mine were mapped, together with some Type D dykes, as the <u>brown porphyry</u>. Brown porphyry dykes are emplaced with variable northerly strikes in the Guichon quartz diorite. In the Trojan breccia pipe they are strongly brecciated and fragmented and are more or less confined to the southern and eastern parts of the pipe, as indicated on the map and cross-sections (see Figs. 14 and 16). Seen in drill core, brown porphyry occurs in the breccia pipe in a manner suggesting that prior to brecciation it existed as numerous closely spaced dykes and sheets, whose attitude is now difficult to discern. Weathered brown porphyry has a reddish brown colour apparently resulting chiefly from a content of hematite in the plagioclase feldspars and persisting in places to considerable depths. The colour of unweathered, altered porphyry is variously grey, green, and white. In spite of a prevalent strong hydrothermal alteration at the breccia pipe, the brown porphyry exhibits largely the same textures and composition as the Krain porphyry, and its appearance in the aplitic variety is illustrated in Plates II h, V i, and V l. About 4,000 feet south-southeast of the Trojan mine a single Type C dyke is lithologically of this type and is the most southerly representative of the Krain-type porphyries to be recognized.

Gnawed Mountain Porphyry: This rock forms dykes and irregular larger bodies in a zone extending west-northwestward from Gnawed Mountain to the Lornex deposit, a distance of about 3 miles. One or more other dykes occur about 2 miles farther north on the Bethsaida property, and a remarkably long dyke system, named the Spud Lake dyke system, extends northward across Highland Valley from Gnawed Mountain to Copper Lake, a distance of more than 5 miles. These dykes and other bodies intrude variously the Bethsaida granodiorite, or porphyritic granodiorite, and older rocks and are intimately associated with breccias at several places.

Typically this porphyry possesses quartz phenocrysts of sizes exceeding 1 centimetre and therefore as large as those in rocks belonging to the Bethsaida stock, and, especially where strongly altered, it is distinguished only with difficulty from the Bethsaida porphyritic granodiorite and porphyry. In distinction to the latter the Gnawed Mountain porphyry seldom possesses biotite phenocrysts larger than 2 millimetres. The rock is generally coloured white, grey, or faintly pink and it contains phenocrysts amounting to approximately half its volume and including ones variously of quartz, plagioclase, biotite, and less commonly hornblende.

Quartz phenocrysts rarely reach a size as large as 2 centimetres, are mostly poorly shaped, rounded, and embayed, and may contain white feldspathic inclusions. In some outcrops the quartz crystals resist weathering and show up as knobs. Plagioclase phenocrysts are very strongly zoned and they reach 1 centimetre in size. Biotite phenocrysts are small, thick, and scarce; at Gnawed Mountain they are partly recrystallized hydrothermally to biotite aggregates. Depending on the conditions of emplacement of the rock, its groundmass is either dense and aphanitic or holocrystalline and aplitic. If aphanitic, the rock may exhibit small, second generation phenocrysts which accompany the larger ones, in the manner described for the P_3 porphyry. Embedded in the groundmass are small amounts of accessory minerals such as sphene, apatite, and magnetite. Where aplitic, the groundmass is seen under the microscope to consist mainly of quartz, plagioclase, and lesser potash feldspar as an interlocking mosaic of anhedral grains whose average size is generally about 0.1 millimetre, but may be either larger or smaller. Features peculiar to the individual porphyry bodies are referred to in the following descriptions of these bodies, which are dealt with in their order of occurrence, mainly from west to east.

In trenches on the Bethsaida property between 1 and 2 miles farther east, porphyry with large quartz phenocrysts occurs as two or more dykes possibly with east-northeasterly strikes. Transition of this porphyry to breccia was noted by White et al. (1957, p. 5). Other quartz porphyry dykes were recently noted in underground workings at the Valley deposit, which is about 1 mile to the northeast of these occurrences (personal communication from W.J. McMillan, 1969). Extending for as much as 3,000 feet along the southwest limit of the Lornex deposit and intersected by drill holes and the Discovery zone trenches (see Minister of Mines, B.C., Ann. Rept., 1966, Fig. 25) are irregularly shaped, sizeable bodies of quartz porphyry that were emplaced in the Bethlehem quartz diorite possibly after formation of one or more northwesterly trending faults which are apparently truncated by the porphyry. The porphyry seen in the trenches, although shown by drill holes farther south to pinch out locally upward, probably continues southward toward exposures of breccia east of the Lornex baseline at 34 south. The breccia is cut by narrow stringers and dykes of the porphyry which, farther west, forms separate dykes that are emplaced in the Bethsaida granodiorite near the edge of the stock at the locality of drill hole No. 6 (see Minister of Mines, B.C., Ann. Rept., 1966, Fig. 25). Between these exposures at Lornex and those mapped to the east-southeast on Gnawed Mountain is a gap of approximately 1 1/2 miles, about which little is known and where quartz porphyry bodies may occur.

On Gnawed Mountain, a confusion of identity of this porphyry and the Bethsaida rocks which existed at the time of field work in 1962 has only partly been resolved by excellent recent company mapping. Consequently the areas occupied respectively by the map units (4) and (5) on the accompanying map (Fig. 3) may be partly in error. Information from all sources, including underground observation at the Highmont mine, nevertheless makes it fairly clear that porphyry bodies of unit (5) include variously: An irregular-shaped body which more or less enclosed the western, or Minex, breccia pipe; rare dykes a few tens of feet wide which strike in various easterly directions and are emplaced in the Bethlehem quartz diorite north of the Bethsaida prong in the Highmont workings and in drill holes on the A.M. No. 32 fractional claim, and south of the prong on the Ann No. 3 mineral claim; and a north-trending dyke lying 1,300 feet east of the summit of Gnawed Mountain which is part of the Spud Lake dyke system. Possibly other bodies of this porphyry are represented by dykes extending variously north and south from the largest breccia pipe near the summit.

The porphyry body around the Minex breccia pipe is an irregularly shaped mass measuring possibly as much as 2,000 feet in length in a west-northwesterly direction. It is emplaced mainly in the Bethsaida porphyritic granodiorite and locally on the south in the Bethlehem quartz diorite and it grades centrally into the breccia of the pipe. The texture is mostly aplitic, and near the edge of the body, becomes finer grained and partly aphanitic. The rock is cut by countless intersecting fractures, and it contains biotite which is mostly recrystallized to form fine-scale aggregates. Narrow irregular dykes of similar aplitic porphyry, only a few feet wide, occur as far east as the A.M. No. 32 mineral claim, and are probably offshoots of this body.

The derivation of fragments of both aphanitic and aplitic porphyry in the large Gnawed Mountain breccia pipe, which lies a few hundred feet distant farther southeast, may be from hidden bodies of either the Bethsaida porphyry or the porphyry now under discussion, both of which form small outcropping bodies in the vicinity of the pipe.

The extensive Spud Lake dyke system, which outcrops 600 feet to the east of the Gnawed Mountain breccia, has more or less similar characters throughout its 5-mile length. It probably consists of a single main dyke, which may be fully continuous, accompanied locally by adjacent narrower dykes. Outcrops south of Highland Valley are distributed at intervals along a northerly distance of about 2 1/2 miles, of which only the southern part is shown on Figure 3, and are separated by a covered interval of about 2 miles from a long series of outcrops north of Highland Valley near Spud and Copper Lakes. The whole system is emplaced in variously the Guichon and Bethlehem quartz diorites and it possesses more or less steep westerly dips and a strike that is slightly east of north, although the strike of the main dyke locally changes to either side of north. The main dyke ranges from about 50 feet to 150 feet wide and it locally pinches, swells, and rarely jogs a few feet or tens of feet in either direction, but mainly left-handed. These jogs follow the directions of pre-existing sets of predominant fractures in the host quartz diorites. Chilled grey, green, or pink selvages as much as 10 inches wide occur at the walls, and in many places the porphyry retains an aphanitic texture throughout the width of the dyke. Locally the centre of the dyke possesses an aplitic texture. Phenocrysts comprise between 25 per cent and 45 per cent of the rock and are of more than one generation, of which the largest includes quartz phenocrysts rarely as large as 2 centimetres and partly of angular, euhedral appearance. Biotite occurs in larger plates and books (reaching a size of one-half centimetre) in the northern outcrops than in the southern ones, which likewise differ in containing lesser amounts of hornblende. Apatite forms one-half-millimetre crystals in the northern outcrops.

At four or more localities south of Highland Valley, of which two are shown on Figure 3, porphyry breccia is developed partly at jogs in the main dyke or subsidiary dykes. Adjacent along strike from these breccia bodies the chilled selvage of the porphyry dyke consists of broken phenocrysts in a glassy matrix, as illustrated by Plate Vi, and affords evidence that the breccia formed in conjunction with emplacement and cooling of the porphyry intrusion. A chemical analysis and normative composition of a sample of this selvage are given in Table III, D.

Other Quartz Porphyries (not known as breccia-forming.)

Crowded Porphyry: Possessing closely packed phenocrysts which give it a crowded texture in the field, this fairly distinctive rock type (marked A on the map, Fig. 3) is confined in this area to the Bethlehem property and was originally termed quartz diorite porphyry (White, *et al.*,1957, p. 6). It forms a braided system of partly interconnected dykes in the vicinity of the Bethlehem orebodies, more or less central in the swarm (*see* Fig. 3, 8, and 10). The system is traced northward for about 1 1/2 miles from the Iona orebody toward One Loon Lake, and it contains as many as seven dykes spaced across a maximum distance of three-quarters of a mile. Individual dykes possess widths commonly between 40 and 60 feet, although at dyke junctions the total width of the intrusion may be as great as 200 feet. Although somewhat irregular in both dip and strike, the dykes possess dips which are generally westerly and steep and strikes which range mostly about a direction which is east of north. The dykes were emplaced later than the P_3 porphyry, breccia, and dykes of Unit No. 7 which they penetrate and are chilled against. The Crowded porphyry dykes are themselves penetrated by later quartz latite porphyry dykes in the East Jersey orebody. One or more dykes of a comparable Crowded porphyry, which apparently differs only in its lack of epidote, occur well beyond the Highland Valley map-area on the Chataway property in diamond-drill holes about 3,000 feet south of Dot Lake.

The Crowded porphyry is only weakly fractured and mineralized, and it mostly forms blocky, massive outcrops and pit exposures. North of the Iona orebody this porphyry is sheared and consequently forms rubbly outcrops which are buff-coloured due to weathering and possess rough, pitted surfaces. Elsewhere the rock appears variously flesh-coloured, grey, or green, and in all places it contains epidote in more or less conspicuous aggregates as much as 1 centimetre across. Together the epidote aggregates, the crowded phenocrystic appearance, and the presence of quartz phenocrysts serve generally to identify the Crowded porphyry (see Plate III a), whose strongly chilled selvages and stringers alone fail to show these features and instead show small phenocrysts mostly of feldspar and quartz which are set in an abundant pink or brown aphanitic matrix (see Plate V k).

In typical crowded-textured rock towards the centre of most dykes, the aphanitic matrix gives way to a holocrystalline groundmass composed of subhedral to shapeless crystals mostly of plagioclase and quartz in semi-poikilitic or enclosing texture, with no recognizable K-feldspar. This groundmass is less abundant than the phenocrysts, which amount to as much as 70 per cent by volume of some porphyry samples. As shown by a modal analysis (Table 1), plagioclase phenocrysts comprise about one-half the volume of the rock; they may equal three-quarters of a centimetre in size, are commonly partly sericitized and otherwise altered yet they retain evidence of an oscillatory normal zoning which, according to optical measurements, causes a compositional variation of between An_{48} and An_{28}. Quartz phenocrysts are fewer and smaller, being rarely larger than 4 millimetres, and they exhibit rounding and embayments probably due to resorption at high intrusion temperatures. They may also exhibit a narrow white or pale pink mantle, which is seen with a pocket lens and is resolved under the microscope as a rim of feldspathic particles which are enclosed in the quartz. Similar feldspathic particles locally form aggregates in the interior of the quartz phenocrysts, where they show up as pale inclusions seen with a pocket lens. Other phenocrysts are variously: Hornblende, whose partly sieve-like crystals are altered largely to the conspicuous aggregates of epidote, calcite, and chlorite; biotite, as rare chloritized plates and thin books reaching a size of 4 millimetres; and occasional small phenocrysts of apatite and sphene.

Xenolithic Quartz Latite Porphyry: The single known occurrence of this quartz porphyry is between 201 feet and 229 feet in Bethlehem diamond-drill hole No. B77, which is at the north end of the East Jersey orebody, as shown on Figure 8. The porphyry occurs in the Guichon quartz diorite only a foot or two distant from a large Crowded porphyry dyke whose emplacement could have largely obliterated any existing porphyry and could thus account for the apparent limited extent of the xenolithic porphyry. The xenolithic porphyry is an aphanitic, pinkish rock containing abundant partly rounded fragments of the Guichon quartz diorite and also phenocrysts, some as large as 4 millimetres which are variously of white- to flesh-coloured plagioclase that is partly rimmed by pink K-feldspar; dark green hornblende as well-shaped crystals enclosing small plagioclase laths in sieve-like fashion; and quartz as small rounded and embayed grains with minute pink inclusions, which are of groundmass material. As seen under the microscope, some plagioclase and quartz phenocrysts are fragmental and broken and the groundmass of the rock is a mixture of glass and fine-grained crystals which are mostly quartz and K-feldspar. The clastic groundmass, broken phenocrysts, and quartz diorite fragments together indicate that this porphyry is auto-brecciated and differs only to a degree from explosion breccia.

Sheba Aplitic Porphyry: A 150-foot wide light-coloured dyke trending north 10 degrees east occurs in outcrop 1,500 feet due west of the cabin on the Sheba road, south of Highland Valley on or near the Dawn No. 5 mineral claim. So far as known this dyke (marked B on the map) is unique in the area and by lacking phenocrysts of K-feldspar, it differs from rocks known as "Roscoe granite," which occur northeast of Gnawed Mountain. The Sheba porphyry dyke is emplaced in the Bethlehem quartz diorite without development of an aphanitic selvage and it contains phenocrysts as large as one-half centimetre, variously of quartz, strongly zoned plagioclase, booky and platy biotite, and sieve-like hornblende. The holocrystalline groundmass amounts to 60 per cent of the rock and, under the microscope, is seen to be an aplitic mosaic largely of quartz and plagioclase grains together with biotite and also orthoclase, which forms less than 10 per cent of the rock. Malachite was seen in the adjacent quartz diorite and C.S. Ney records bornite veinlets near the west contact of the dyke (see Assessment Report No. 242, p. 6).

This dyke adjoins a steep rock gully which is itself part of a topographic lineament that extends north-northeast for several thousand feet to the start of superficial deposits which mantle the floor of Highland Valley.

Lornex Felsite Porphyry: Known only in a few Lornex drill holes this creamy or white aphanitic quartz porphyry contains scattered 2 millimetre-sized plagioclase phenocrysts and rarer ones of quartz, and is apparently later in age than the Gnawed Mountain quartz porphyry or alternatively the Bethsaida porphyry, which forms the main porphyry masses that occupy the Discovery zone trenches and the edge of the Bethsaida stock due west of the Lornex shaft. West of the shaft from 656 feet to 833 feet in diamond-drill hole No. 49, the felsite porphyry is intersected immediately east of a major fault which here bounds the east edge of the Bethsaida stock. The intersection shows the felsite porphyry to be somewhat altered and mineralized only with pyrite and possibly molybdenite and its eastern part to be a breccia in contact with an adjoining body of the Gnawed Mountain quartz porphyry, of which fragments occur in the breccia (see Minister of Mines, B.C., Ann. Rept., 1967, p. 157). Similar porphyry, but with rare small hornblendes, occurs as stringers cutting the Bethlehem quartz diorite farther east on this drilled section at 451 feet in hole No. 12. At the Discovery zone in drill hole No. 48, at 894 feet and elsewhere, stringers of the felsite porphyry are seen to cut the Gnawed Mountain quartz porphyry, which alone is mineralized with bornite and chalcopyrite. Breccia occurs nearby in hole No. 48.

Unclassified Quartz Porphyry Dykes: Approximately 18 mapped dykes, mostly marked B on the map, consist of quartz porphyry lacking the distinguishing characters of the varieties already described.

Three of these dykes are located south of Highland Valley, the most westerly being a dyke seen underground at the Alwin (O.K.) mine, which is about 20 feet wide and possesses a north-northwesterly strike and a moderate easterly dip. This dyke, which is not shown on Figure 3, has sharply defined, irregular, chilled margins against the enclosing Bethsaida granodiorite and locally against breccia, which it evidently post-dates. The dyke rock is grey, altered, and aphanitic, and it contains quartz phenocrysts of moderate size and rare biotite books, which are altered. These phenocrysts are accompanied by others variously of plagioclase and apatite and by quartz fragments as large as one-half inch. The dyke interrupts some fractures in the granodiorite which are therefore earlier and may in places have carried vein quartz from which the observed fragments were apparently derived.

A grey aphanitic hornblende quartz porphyry is intersected in Highmont diamond-drill hole No. 9 on the A.M. No. 4 claim northwest of Gnawed Lake and, nearly one and one-half miles farther north, a northeast-striking dyke is poorly exposed about 2,750 feet due east of the camp on the Sheba road. The latter dyke, which is referred to in Assessment Report No. 242, resembles more or less the Spud Lake quartz porphyry dyke whose projected location lies several thousand feet farther east. The remaining dykes are distributed widely in the swarms north of Highland Valley and they mostly strike northwestward, although some are north to northeast striking. They share a general resemblance, being mostly grey aphanitic porphyries weathering to darker shades and exhibiting a somewhat crowded texture due to a preponderance of pale- to flesh-coloured plagioclase feldspar phenocrysts as much as one-half centimetre in size. These crystals are accompanied by others variously of hornblende and quartz. The hornblende phenocrysts are generally altered partly to epidote, and the quartz phenocrysts rarely exceed 2 or 3 millimetres and are mostly rounded, embayed, contain pale inclusions, and may be difficult to identify if mantled with adhering groundmass material. The three most southwesterly dykes which are emplaced variously in the Beaver and Bethlehem quartz diorites to the south of South Forge Mountain, are distinguished by quartz phenocrysts that reach one-half centimetre in size. Under the microscope all dykes appear to some extent altered, with the consequent production of sericite, epidote, and chlorite, and they are apparently dacites which contain little or no K-feldspar. Their accessory minerals include apatite, sphene, and magnetite. Small amounts of variously pyrite and chalcopyrite were observed in some of the dyke outcrops.

Feldspar Porphyries

These porphyries are characterized by a lack of conspicuous quartz phenocrysts and they form dykes that are apparently restricted to that part of the swarm lying north of Highland Valley. They include Type D and Type E porphyries and other undesignated porphyries of unit No. 7.

Type D Porphyry: This type is distinguished from other feldspar porphyries mainly by the appearance of its groundmass which, although very fine grained and classed as aphanitic rather than holocrystalline, is sufficiently crystalline to be crudely resolvable with a pocket lens and to have a characteristic appearance under the microscope (see Plate V 1). Sparse, inconspicuous quartz phenocrysts not exceeding 1 millimetre in size may be present and are commonly mantled by a white siliceous rim. Invariably present are zoned plagioclase phenocrysts all less than one-half centimetre in size and also lesser numbers of comparably large, dark green hornblende phenocrysts that are well shaped, partly sieve-like due to enclosed small feldspars, and partly needle-like or elongate. Biotite is invariably absent. The phenocrysts are exceeded in amount by the groundmass which commonly makes about 60 per cent by volume of the rock. The groundmass is glassy in the narrow dykes or in chilled selvages of the other dykes, but elsewhere it has the murky, sub-granular texture that is characteristic of this type of porphyry.

The dykes weather in outcrop to various colours including white, brown, and pink, and they possess chilled selvages several inches wide that are also of various colours. The freshly broken porphyry appears variously grey or green, or, where influenced by a so-called leuco-alteration on parts of the Bethlehem property, a pale grey-white. Some of the more northerly dykes possess a faintly pink groundmass that is caused other than by K-feldspar, which is more or less absent in this type of porphyry. Epidote resulting from alteration is quite commonly disseminated and small amounts of sulphide may likewise occur. Aplite veins were observed in this porphyry only on the S.J. No. 19 mineral claim on the Bethlehem property, and their significance is unknown.

Features seen under the microscope include fine-scale textures involving quartz and plagioclase, which are delicately intergrown as fringes on crystals of variously plagioclase and quartz, or which occur as quartz shapelessly enclosing plagioclase tablets. Much of the rock consists of small crystals which are mostly of plagioclase and also variously of hornblende, quartz, sphene, apatite, and magnetite. Staining of etched thin sections with sodium cobaltinitrite failed to show the presence of any K-feldspar. The measured specific gravity of a sample of Type D porphyry from a dyke at the S.B. trenches is 2.67 (<u>see</u> Table II).

Type D porphyry dykes occur most abundantly in a part of the Bethlehem property that is centred on the open pits and measures about 9,000 feet in both northerly and easterly directions. Some of these dykes are traced individually for distances of as much as 2,000 feet. Commonly the more easterly occurring dykes possess northerly strikes and the more westerly occurring dykes possess strikes that are east of north. Dips are mostly steep and commonly are easterly for the easterly occurring dykes and westerly for the westerly occurring dykes. During mapping of the property these dykes were designated P_1 and, in lesser numbers, P_2 and were recognized in places as cutting across and, therefore, later than the P_3 porphyry and associated breccia. They were also seen to be cut by and, therefore, earlier than dykes of the Crowded porphyry. Possibly not all the Type D dykes on the Bethlehem property are of similar age, and some of them may pre-date breccia because abundant feldspar porphyry fragments are incorporated in the Bethlehem breccias.

The remaining Type D dykes are distributed throughout the length of the swarm northward from the Bethlehem property and all possess strikes that are either northwesterly or northerly, with one exception which is a northeast striking dyke located at the east side of the swarm about 7,000 feet due east of the Trojan mine. The unusually weathered and discoloured state of porphyries at the Trojan mine has impeded proper recognition of porphyry types within the field category of brown porphyry, which is now known from collected specimens to include Type D material, partly as porphyry fragments which are incorporated in the breccia pipe. Type D dykes therefore pre-date the Trojan breccia, at least in part.

Type E Porphyry: Dykes lettered E on the map (Fig. 3) are not strictly of one type although most are of a distinctive feldspar porphyry containing small, elongate hornblendes and a pinkish groundmass which is variously glassy or possesses a sub-aphanitic, murky appearance similar to the Type D porphyry. Other dykes in this group are miscellaneous feldspar porphyries.

Foot Lake Porphyries: At the eastern limit of mapping 1 1/2 miles north of Highland Valley near Foot Lake, two or more dykes occur separated from the main swarm and consist of porphyries not represented in the main swarm. The dykes (marked F on Fig. 3) trend northward about one-half mile apart and are each of unknown width exceeding several feet. Where exposed they are emplaced in the Guichon quartz diorite. Probably a single eastern dyke is represented by two outcrops lying about one-half mile apart in a northerly direction and consisting of porphyry with relatively few phenocrysts and an abundant pinkish grey groundmass that includes crowded small crystals. The phenocrysts reach a size of one-half centimetre and are variously squat white plagioclases, elongate hornblendes, and smaller flakes and books of biotite. The most conspicuous crystals in the groundmass are minute needle-like hornblendes which, together with accompanying plagioclase laths, impart an appreciable foliation or flow texture to the rock.

Under the microscope the rock shows features which include: a strong zoning of the plagioclase; the presence of small, irregularly shaped quartz phenocrysts with inclusions; and holocrystalline groundmass which includes minute interstitial quartz grains amounting possibly to 5 per cent by volume of the rock; and occasional phenocrysts consisting of a core of biotite and an envelope of hornblende which apparently record a reversal of the usual order of crystallization of these minerals, perhaps in consequence of some local metamorphic event which is otherwise unknown.

In both its outcrops this porphyry encloses mainly small subangular to rounded fragments of a white rock which, judging from collected specimens, is a porphyry with a crowded texture and is composed predominantly of weakly zoned plagioclase tablets as much as 2 millimetres in size with discontinuous rims of K-feldspar, small scattered biotites and scraps of hornblende, accessory magnetite and sphene, and a very sparse interstitial groundmass of quartz and feldspar that is holocrystalline and fine grained.

The western dyke, which is close to Foot Lake, is similar to the eastern dyke in possessing elongate hornblendes and differs from it in being a pinker rock with more or less conspicuous quartz phenocrysts and a very fine-grained aplitic groundmass consisting of quartz, plagioclase, and K-feldspar. Its margins are holocrystalline and, therefore, not severely chilled against the host quartz diorite. The porphyry is hydrothermally altered, contains secondary biotite, and is mineralized by disseminated chalcopyrite in very small amount.

Breccias

General: These fragmental rocks are emplaced in conjunction with the breccia-forming porphyries variously in the Guichon and Bethlehem quartz diorites and the Bethsaida granodiorite. Breccia localities at Gnawed Mountain and the Bethlehem, Trojan, and Krain properties, respectively, are spaced at decreasing intervals in the north-trending zone of breccia-forming porphyries, and breccias near Gnawed Mountain and south of the Lornex deposit are aligned on a west-northwest-trending zone of these porphyries (see Fig. 5). Elsewhere small breccias occur variously along the north-trending Spud Lake dyke system, which passes east of Gnawed Mountain, and at the Alwin mine and possibly also on the Bethsaida property (White et. al., 1957, p. 5).

The largest breccia bodies are those at Gnawed Mountain, Bethlehem, and Trojan, some of which measure as much as 2,000 feet long and several hundred feet across. In general the bodies possess irregular, steep contacts which variously are well-defined or grade into veined and fractured wallrock. Mostly the bodies are elongated parallel to accompanying porphyry intrusions, and they extend to depths in some cases known to exceed hundreds of feet (see Bethlehem and Trojan cross-sections, Figs. 10 and 16).

Breccia is generally a dense, tough rock without voids and consisting of rock fragments in a fine-grained matrix, which is mostly plentiful enough to prevent almost all contact between the fragments (see Plates III b, c, d, and IV a, b, c). Locally veins of this matrix penetrate undisplaced, fractured rocks that form either the walls of the breccia bodies or screens within the bodies. The colour and appearance of the breccias vary according to their composition and degree and type of alteration. Mostly these rocks are predominantly grey or green, but some are nearly pure white and others are altered to reddish tints.

The fragments are mostly of the rock types which form the walls of the breccia, principally the quartz diorites and granodiorite together with one or more porphyry types. Fragments of one type generally far exceed in volume those of other types, but the predominant type may change across the breccia body. Some of the breccia may consist entirely of brecciated porphyry and grade to a mixed breccia containing varied fragments of random orientation. Even in this mixed breccia there is evidence that the relative movement of fragments in places was limited. Thus, locally fragments may be found fitting roughly together and preserving the form either of narrow porphyry dykes or of veins of altered rock for short distances in the breccia (see Plate IIIc). Fragments mostly range in size from one-half inch to 2 or 3 feet, and blocks much larger than this probably represent virtually undisplaced wallrock. The size and shape of the fragments is partly related to rock type, so that the medium-grained quartz diorites and granodiorite mostly form rounded to sub-angular shapes as much as several feet in dimension (see Plate IVc), and the porphyritic varieties of these rocks mostly form tabular, slab-like, or angular fragments of small to moderate size (see Plate IVb). Porphyry fragments are generally small, angular to sub-angular, and rarely exceed 6 inches in size except for those of brown porphyry in the Trojan breccia, which partly form large blocks. Porphyry fragments have several appearances, being variously aphanitic and aplitic; pink, grey, green or dark in colour; and partly exhibiting quartz phenocrysts. Fragments are occasionally seen of quartz diorite and porphyry which contained aplite veins prior to brecciation.

In addition there are fragments, generally small in size and number, which are of unusual types. These variously include pink or white aplite; barren vein quartz; biotitized fine-grained rock probably representing an early-formed breccia matrix; and rocks only partly identifiable as to origin which now consist mainly of quartz, epidote, tourmaline, chlorite, and other alteration products.

The matrix is a dense, fine-grained material which is commonly pale to dark grey or green in colour but which varies partly because of alteration. Locally it forms as much as 60 per cent by volume of the breccia, or as little as 5 per cent. In its freshest condition it is mostly a silt- to sand-sized, crudely aplitic mosaic of welded particles mainly of quartz and feldspars, with other minerals present such as chlorite, magnetite, apatite, and sphene. It includes abundant rock chips and scattered crystals and broken grains variously of quartz, feldspars, and occasionally biotite, that are evidently derived partly from porphyry phenocrysts (see Plates V j and m). The southern breccias at Gnawed Mountain and near Lornex partly contain scattered crystals variously of K-feldspar and chloritized biotite, while those of the Spud Lake dyke system possess scattered hornblendes and biotites. Compared to much of the breccia occurring north of Highland Valley, in which the average particle size of the matrix is approximately one-quarter millimetre, the southern breccias mainly possess a matrix which is coarser grained, possesses a high proportion of potash feldspar, and encloses larger scattered crystals, whose size is partly one-half centimetre and corresponds to that of phenocrysts in the associated porphyries. Rock alteration in the breccias is partly restricted to the matrix. A fine scale biotitization affects much of the matrix of the Iona and Jersey breccias and colours it brown. The biotite is a variety pleochroic in browns that appears similar to the primary biotite of the accompanying intrusive rocks, and it is therefore probably a late magmatic product related to the act of porphyry intrusion and breccia formation. K-feldspar and quartz were apparently introduced during partial recrystallization of the matrix in some northern parts of the Jersey and East Jersey breccias, and the matrix now crudely resembles a granophyric aplite except for the presence of rock chips. Tourmaline is absent from breccias near Lornex and at Alwin but is more or less widely present in the other breccias, and it occurs principally as a disseminated replacement of the matrix which is thereby partly blackened. In many breccias quartz is partly introduced or segregated in places in the matrix, and chlorite forms abundant meshes in the matrix as well as occurring more generally in the rocks (see Plate Vn). The chlorite is partly a strongly birefringent variety distinct from the accompanying penninite variety.

In addition to the above effects, rock alteration is partly pervasive in the breccias as in other rocks of the area, and it is described in a subsequent section. The occurrence in several breccias of rocks that were variously altered before their incorporation in breccia indicates that rock alteration spanned the period of breccia formation. Some of the altered fragments are of recognized wallrock types; for example, porphyritic quartz diorite at Bethlehem and rhyolite porphyry at the Trojan mine.

Bethlehem Breccias: Breccias on the Bethlehem property occur at intervals for 7,000 feet along an irregular, northwest-trending contact between the Guichon and Bethlehem quartz diorites, from the White zone in the southeast through the Iona, East Jersey, and Jersey orebodies as far to the northwest as small breccia occurrences in the 4600 level adit (see Fig. 3). To date no breccia is reported from the Huestis orebody, which lies immediately south of the last mentioned occurrences. The breccia bodies mostly possess a more or less northerly elongation and are relatively narrow, being related to the emplacement of individual branching sheets of a single P_3 porphyry intrusion. As mapped, the Iona breccia is the largest body and measures as much as 1,000 feet wide and 2,500 feet long, but probably this body too could be separated by more detailed mapping into various smaller bodies separated by screens of relatively unbrecciated rocks. The form and relations of the principal Bethlehem breccias are illustrated by various maps and cross-sections (see Figs. 3, 8, 9, and 10) and these breccias need no individual description except for certain details relating to their place in the sequence of geological events.

A type of alteration subsequently described and termed leuco-alteration (see White et. al., 1957, p. 8), is recorded on the Bethlehem property mainly in the Bethlehem quartz diorite and porphyries between the Iona and Huestis orebodies. Conspicuous, bleached fragments scattered in the Bethlehem breccias apparently consist of leuco-altered Bethlehem quartz diorite and therefore indicate that the leuco-alteration partly preceded the brecciation.

The possibility of two stages in the production of breccia at Bethlehem is shown by the occurrence in the Iona breccia of fragments of a pre-existing breccia. These fragments consist of quartz diorite fragments embedded in an early breccia matrix, which is coarser grained than the prevalent Iona breccia matrix. Other small, dark fragments in the Iona breccia probably also represent a fragmented matrix, apparently of the same uniformly fine-grained type that occurs across a width of a few inches between P_3 porphyry and breccia in the 4600 level adit at the western edge of the Jersey orebody (see the cross-section, Fig. 10). Additional evidence of the existence of two stages of brecciation in the Iona body is an occasionally crosscutting relationship seen between one type of matrix and an apparently earlier type.

Trojan Breccia: This breccia body, one of the largest in the mapped area, lies 3 miles north of the Bethlehem breccias and is nearly 1,000 feet wide in places and as much as 1,200 feet long in a northerly direction. As shown by the map and vertical sections (Figs. 14 and 16), it is largely steep-walled and contains a steep, sinuous and partly narrow, braided intrusion of the Trojan rhyolite porphyry. In consequence of underground examinations made since the accompanying figures were prepared, the mapped location of part of the western wall of the breccia body near the shaft is somewhat amended in the Annual Report for 1967 (Fig. 19).

The breccia includes mainly three types of fragment, which are respectively of the Guichon quartz diorite, the rhyolite porphyry, and the brown porphyry. All three may be present together or, alternatively, one or other of the porphyries may be lacking. The distribution of the brown porphyry fragments is shown, and partly it covers large portions of the breccia body in which rhyolite porphyry fragments are sparse or lacking. Rhyolite porphyry fragments occur chiefly in parts of the breccia more or less adjoining the rhyolite porphyry intrusion, some of whose branches are well-nigh completely brecciated and alternate with mixed breccia to form a multiply sheeted mass. Similar multiple sheeting occurs elsewhere in the breccia body and involved brecciated dykes of the brown porphyry and brecciated screens of the Guichon quartz diorite, alternately. The brown porphyry dykes partly possess preserved chilled selvages and they range in width from a few inches to tens of feet, and the spacing also varies and is partly close. Since much of this information is derived from drill core the attitude of the dykes and sheets is generally unknown. Parts of the breccia body, especially toward its walls, consist of weakly brecciated quartz diorite traversed by widely-spaced veins of matrix in which porphyry fragments are rare or absent. A few fragments at places indicated on the map (Fig. 14), were identified as of the Bethlehem porphyritic quartz diorite, of which only a single small outcrop occurs near the Trojan breccia.

Rhyolite porphyry sheets and fragments commonly exhibit a strong alteration, which colours them variously pink, buff, and light-green and was effected prior to brecciation. X-ray identification of the fine-grained argillic products of this alteration confirmed the presence of much sericite and chlorite, which are accompanied chiefly by quartz.

The matrix of the breccia is diversely altered and therefore varies considerably in composition. In the brecciated rhyolite porphyry it consists largely of fine-grained quartz and sericite, with rare contained quartz grains as large as 2 millimetres, but elsewhere the matrix material is different (see Plate Vn).

The described differences in fabric and composition of the Trojan breccia from place to place suggest that its origin was complex and possibly occurred in more than one stage.

The brown porphyry undoubtedly preceded the rhyolite porphyry and it evidently was emplaced in fractured quartz diorite and may have caused a first stage of brecciation. Evidence was seen in drill core that rhyolite porphyry stringers were in places intruded into a pre-existing breccia, whose origin may possibly thus be related to the emplacement of the brown porphyry.

Krain Breccia: Illustrated by Plate III d, this breccia is associated with the central occurrences of the Krain porphyry and makes two exposures separated by 30 feet of porphyry and totalling 50 feet in combined length along an access road 1,200 feet to the south-southwest of the Krain camp (see Fig. 18). The breccia which is probably limited in size, apparently occurs on either side of a northwesterly dyke at its fork with the main dyke of Krain porphyry, whose brecciated, chilled selvage against the Guichon quartz diorite farther north has been analyzed (Table III, E). No breccia was seen at similar forks between dykes at the southern porphyry occurrences nor was any seen in the Krain mineralized zone, which lies immediately north of the camp. The breccia contains fragments chiefly of the Guichon quartz diorite and of porphyry, which is partly readily identifiable as the Krain porphyry. The outcrops are weakly mineralized with pyrite and trace amounts of chalcopyrite.

<u>Minex Breccia and Gnawed Mountain Breccia</u>: These lie about 2,000 feet apart (<u>see</u> Fig. 3). The western, or Minex, breccia lies mostly on the Ide No. 2 mineral claim, is of the order of 400 feet wide, and is roughly circular. It is more or less enclosed at surface by a body of the Gnawed Mountain porphyry which extends principally eastward and is strongly crackled and partly brecciated in that direction. The Minex breccia is largely of sericitized and otherwise altered porphyry fragments in a matrix that is widely tourmalinized, quartz-veined, and partly mineralized with specular hematite and chalcopyrite.

Fragments of vein quartz were noted in the breccia, and other fragments may represent the Bethlehem quartz diorite, whose outcrops are nearby.

Breccia occurs in association with a porphyry dyke in the Highmont adit and east drift some 400 feet below and 500 feet north of the Minex breccia (<u>see</u> <u>Minister of Mines, B.C.</u>, Ann. Rept., 1968, p. 190).

The eastern, or Gnawed Mountain, breccia is one of the largest in the Highland Valley area, measuring as much as 2,000 feet long and 600 feet wide in places. It occupies high ground mainly on the Ann Nos. 1, 2, and 4 mineral claims and it is emplaced with a west-northeasterly elongation more or less along a contact between the Bethlehem quartz diorite to the north and the Bethsaida porphyritic granodiorite to the south. The latter rock grades into, or is cut by, porphyry of either the Bethsaida type or the Gnawed Mountain type which extends as southerly and south-southeasterly dykes for short distances in the nearby Bethlehem quartz diorite. The breccia matrix is partly strongly tourmalinized and it encloses fragments of all the above-mentioned rock types as well as fragments in lesser numbers variously of aplite vein quartz, dark altered rocks, and the Guichon quartz diorite (which is unknown as outcrops in this part of the Highland Valley area). Well-shaped crystals variously of quartz, plagioclase, and K-feldspar are found scattered in the breccia matrix and are apparently derived from porphyry of one or other type.

Breccias of the Spud Lake Dyke System: Two small breccia bodies lie alongside the main dyke of this north-trending system east of Gnawed Mountain (*see* Fig. 3) and two others, known principally from company mapping, lie approximately 800 feet apart some 1 1/2 miles farther north on the J Nos. 37 and 38 fractional claims, respectively. The close relationship of these bodies with the dyke, both spatially and in composition, affords strong evidence of the manner of origin of such breccias. At all occurrences except the northernmost, which is simple a 5-foot-wide breccia dyke, breccia grades rapidly to porphyry in at least one direction and is commonly adjoined in the other direction by the Bethlehem quartz diorite. The breccia is more or less similar to the Minex breccia in composition and it consists largely of porphyry fragments in a very abundant matrix that is locally tourmalinized and contains crystals variously of quartz, plagioclase, biotite, and hornblende similar to phenocrysts in the porphyry. The southernmost breccias are locally veined by quartz with accompanying tourmaline, specular hematite, and rarely chalcopyrite, all of which may occur in vugs. The porphyry dykes undergo jogs, or local changes in strike, which apparently are related to zones of closely-spaced fractures in the host quartz diorite, and breccia is partly located at these places. The largest body of breccia, which is immediately east of the summit of Gnawed Mountain, extends for approximately 600 feet southward along the east wall of the main dyke and is generally only a few tens of feet wide, although it becomes nearly 100 feet wide at the north end where the dyke splits and partly encloses the breccia. Adjacent along strike from this breccia body the porphyry dyke possesses a chilled selvage containing broken phenocrysts, as illustrated by Plate V j, and having the analysed composition given in Table III, D.

Although unnoticed in the present mapping, breccia was reported to occur in association with this porphyry system near Spud Lake also (White et. al., 1957, p. 5).

Breccias near the Lornex Deposit: Breccias of undetermined extent, and not shown on the accompanying map (Fig. 3), lie approximately 1 1/2 miles west-northwest of the Minex breccia at locations immediately east of the Lornex baseline at 34 south (see Minister of Mines, B.C., Ann. Rept., 1966, Fig. 25 for the position of the baseline). The exposures may belong to a single breccia body and they consist of pale-coloured breccias containing fragments variously of altered granitic rock (either granodiorite or quartz diorite), quartz porphyry, granophyric aplite, and vein quartz and cut by stringers of a pale aplitic quartz porphyry possibly similar to large bodies occurring farther north near the Discovery zone. The breccia matrix is fine grained and crudely aplitic, and it consists chiefly of quartz, plagioclase, and K-feldspar enclosing larger crystals of the same minerals. The surrounding area is poorly exposed and incompletely mapped and the relationships of the breccia to other rocks is therefore unknown.

Other minor breccia occurrences intersected by Lornex drill holes are spatially associated with various types of porphyry, as mentioned in a preceding section of this report.

Breccia at the Alwin Mine: Two small occurrences of breccia have been noted in the Bethsaida granodiorite underground at the Alwin mine (see Minister of Mines, B.C., Ann. Rept., 1968, p. 184). The western occurrence at the No. 46 slash apparently contains only granodiorite fragments, whereas the eastern occurrence near the crosscut entry has, in addition, small fragments variously of aplite and of a mineralized sericite-rich rock similar in appearance to that of the high-grade orebodies in the mine. As exposed, the breccia of the eastern occurrence is a few feet wide at most and it grades sharply eastward to fractured granodiorite and is cut off westward by a later quartz porphyry dyke, beyond which it fails to reappear.

Discussion of the Origin of the Breccias: The above-described breccias share the following features which together point strongly to the likely manner of origin of these rocks: (1) A close association both temporally and spatially with porphyry intrusions; (2) derivation of most of the fragments from previously fractured rocks of types that form the walls of the breccia bodies; (3) a consistently fine-grained matrix whose composition is largely similar to that of the associated porphyry intrusion. These and other shared features lead to the conclusion that the breccias resulted from the intrusion of porphyry into cold, well-fractured rocks. Under these conditions the porphyry intrusion spread rapidly as numerous branching dykes and sheets whose surfaces were quickly chilled to form an impervious seal, thus trapping the volatiles being released by crystallization of the remaining porphyry liquid. Explosion of the porphyry dykes and sheets resulted when the mounting internal pressure exceeded the confining pressure exerted by the host rocks. A similar process envisaged for breccias elsewhere has been termed "explosive devolatilization"

(Taubeneck, 1962). Examples of such breccias are apparently numerous in the literature and many exist in various parts of British Columbia; for example, at the mineralized localities of Catface Mountain, Mount Washington, Galore Creek, Salal Creek, Poison Mountain, Copper Mountain, and in the Iron Mask batholith. Breccia similar in appearance to these was apparently produced in the shot chamber during the underground nuclear explosion, Project Gnome (Gard, 1963).

The described Highland Valley breccias may evidently be classified as explosion breccia, as defined by Wright and Bowes (1963, p. 84). Well-fractured rocks that simulate breccia also exist in the area and are considered not to be breccias because little if any mechanical dislocation of material can be inferred in them. For example, Plate IV (d) shows an outcrop of fractured quartz diorite that is shown on some maps as breccia and is part of a fracture zone occurring beyond the eastern limit of the map (Fig. 3) at a distance approximately 1,200 feet beyond the Spud Lake dyke system east of Gnawed Mountain. The fractures form an intersecting system that is emphasized by alteration, giving the rock superficially the appearance of breccia.

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Fig. 2 ?

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TABLE I

MODAL ANALYSES OF SOME HIGHLAND VALLEY ROCKS +
(Per cent Volume)

	Quartz	Orthoclase	Plagioclase	Hornblende	Biotite	Chlorite, epidote & calcite (mainly from hornblende and biotite)	Accessories	Aphanitic groundmass
Guichon quartz diorite	17.7	11.2	52.7	4.75	11.9	n.a.	1.75	n.a.
Beaver quartz diorite*	25	10	54	5	5	n.a.	1	n.a.
Bethlehem porphyritic quartz diorite	25.2	8.5	57.6	3.1	3.7	n.a.	1.65	n.a.
Bethlehem granite (quartz monzonite facies)	33.3	33.0	30.6	nil	2.7	n.a.	0.43	n.a.
Bethsaida granodiorite	18.1	9.4	67.1	nil	4.7	n.a.	0.67	n.a.
Aplitic breccia forming quartz porphyry (P_3)	28.4	6.4	58.5	n.a.	n.a.	5.5	1.2	n.a.
Crowded quartz porphyry	5.1	nil	47.8	n.a.	n.a.	2.3	.7	44.1

+ Determined by R.V. Kirkham, except for those estimated and marked *

TABLE II

SPECIFIC GRAVITIES OF SOME HIGHLAND VALLEY ROCKS *

Guichon quartz diorite	2.77
Beaver quartz diorite	2.68
Bethlehem quartz diorite	2.68 - 2.69
Bethsaida granodiorite	2.67
Breccia-forming quartz porphyry (aplitic P_3)	2.71+
Feldspar porphyry Type D	2.67

* Error ± 0.01

\+ May be unduly high owing to a small content of introduced sulphides.

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K-Feldspar

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Title H.V.

Author JMC

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(caption for Figure 7)

(place on page opposite Table III)

Figure 7.--Chemical comparison of the Bethsaida granodiorite and breccia-forming porphyries at Highland Valley with some average igneous rocks.

A to E -- Highland Valley rocks, as listed in Table III.

1 to 7 -- Average analyses of rocks, from Nockolds, 1954 (tables 1 and 2):

1 -- Average dacite + dacite-obsidian (table 2, VI)

2 -- Average tonalite (table 2, V)

3 -- Average granodiorite (table 2, III)

4 -- Biotite tonalite (table 2, 10)

5 -- Muscovite-biotite tonalite (table 2, 9)

6 -- Average alkali granite (table 1, III)

7 -- Average alkali rhyolite + rhyolite-obsidian (table 1, IV)

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Author JMC
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TABLE III.--CHEMICAL ANALYSES AND NORMS OF BETHSAIDA GRANODIORITE AND BRECCIA-FORMING PORPHYRIES

Chemical Analyses

	A	B	C	D	E
SiO_2	69.90	64.56	67.28	74.20	66.56
Al_2O_3	16.68	17.15	15.86	14.01	14.79
Fe_2O_3	1.10	1.70	0.63	0.33	1.43
FeO	0.94	1.60	0.93	0.66	1.71
MgO	0.68	1.50	1.70	0.70	1.93
CaO	2.98	5.14	3.00	1.18	3.55
Na_2O	4.58	5.53	6.61	4.52	5.23
K_2O	1.63	0.42	0.90	3.61	1.51
H_2O+	0.79	1.24	1.44	0.22	1.79
H_2O-	0.11	0.36	0.30	0.15	0.20
CO_2	0.01	0.03	0.70	0.01	0.56
TiO_2	0.19	0.39	0.33	0.12	0.28
P_2O_5	0.11	0.13	0.14	0.07	0.12
SO_3	0.01	<0.01	0.01	0.01	0.01
MnO	0.06	0.05	0.04	0.03	0.10
Totals	99.77	99.78	99.87	99.82	99.77

Analyses made in laboratory of British Columbia Department of Mines and Petroleum Resources, S. Metcalfe, Chief Analyst.

Norms

	A	B	C	D	E
Quartz	29.75	18.40	17.89	30.39	20.86
Orthoclase	9.63	2.55	5.33	21.35	8.95
Albite	38.68	46.75	55.80	38.19	44.35
Anorthite	14.22	20.64	9.64	5.39	13.07
Corundum	2.17	-	0.47	0.68	-
Diopside	-	3.70	-	-	0.22
Hypersthene	2.31	3.10	4.98	2.54	6.02
Ilmenite	0.33	0.74	0.62	0.23	0.53
Magnetite	1.61	2.66	0.90	0.49	2.74
Apatite	0.23	0.30	0.34	0.17	0.27
Calcite	Tr.	Tr.	1.59	Tr.	1.27
Water	0.90	1.60	1.74	0.37	1.99
Totals	99.83	100.44	99.30	99.80	100.27

A (specimen 60-45)--Bethsaida granodiorite, from large boulder in trench on east side of access road north of the Star showings, Bethsaida property.

B (specimen 60-27)--Aphanitic quartz porphyry (P_3) dyke, 1,400 feet north of Jersey orebody at northeast corner of S.J. No. 103 fractional claim.

C (specimen 60-28)--Chilled edge of same P_3 dyke, locality as for B.

D (specimen 60-70)--Chilled, brecciated edge of quartz porphyry dyke, 1,300 feet east-northeast of Gnawed Mountain summit.

E (specimen 60-60)--Chilled edge of quartz porphyry dyke, (Krain porphyry) on road 1,000 feet south-southwest of Krain camp.