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# GEOLOGY

*of the*

# KENNEDY LAKE AREA

## VANCOUVER ISLAND
## BRITISH COLUMBIA

*by*
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Draw Lake, looking northeast.

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## Summary


The Kennedy Lake area includes a land area of about 27 square miles around the main part of Kennedy Lake, on the west coast of Vancouver Island. It includes parts of the Estevan Coastal Plain and the Vancouver Island Mountains.

The northwest half of the area is largely underlain by andesite lavas of the Karmutsen Group, and the southeast half by batholithic intrusive rocks of intermediate composition. Sedimentary rocks of the Quatsino Formation and mainly pyroclastic rocks assigned to the Bonanza Group form a relatively narrow belt trending northeast through the middle of the area, largely separating the Karmutsen and batholithic rocks. A roof pendant or large inclusion of the Quatsino sedimentary rocks occurs in the batholithic rocks in the eastern part of the area, and is host to the magnetite orebodies of Brynnor Mines Limited. Some Quatsino limestone is infolded in the Karmutsen lavas in the northwest part of the area.

The Quatsino Formation overlies the Karmutsen Group and underlies the Bonanza Group. In the Kennedy Lake area it comprises a lower limestone member, at least 2,000 feet thick, a middle argillite member, 800 feet thick, and an upper limestone member, 350 feet thick. The contacts are gradational. The limestone members contain few impurities and are thick bedded to massive. The argillite is feldspathic and probably tuffaceous. It is thin bedded and commonly is markedly banded by the alternation of beds of contrasting colour. The formation is of Upper Triassic age.

The sedimentary and volcanic rocks have been successively intruded by andesite, an Older Porphyry, the batholithic rocks, a Younger Porphyry, and basalt and gabbro. With the exception of the batholithic rocks, these rocks occur mostly as narrow dykes and sills; a few small stocks of andesite, Older Porphyry, and gabbro are present. The andesite is particularly common in the lower limestone. The batholithic rocks include diorite and tonalites, which appear to be contemporaneous, and granodiorite-quartz monzonite, which intrudes the diorite. A minor part of the diorite, and possibly part of the mafic tonalite, apparently resulted from recrystallization and metasomatism of andesite, but most of the batholithic rocks were evidently intruded as magma. A potassium-argon date of 167 million years was obtained from the granodiorite. The diorite and tonalites are older by from a few thousand to a few million years. A potassium-argon date of 121 million years was obtained from a dyke of Younger Porphyry.

The sedimentary and volcanic rocks were folded about northeast- to north-trending axes. The best-defined folds are a syncline through Salmonberry Mountain, just south of Kennedy Lake, and an anticline in the pendant of Quatsino rocks in the east part of the area. For the most part, these folds plunge gently southwest, but at the mine the anticline is buckled sharply downward and backward. This down-buckle is probably a later structure superimposed on the primary folding.

The rocks have been broken by many faults of small displacement, and by several with displacements measureable in miles or fractions of a mile. The largest strikes north along the foot of Salmonberry Mountain and displaces the Karmutsen-Quatsino contact between 1 and 2 miles to the left. It appears to branch under Kennedy Lake, and to the south it curves away to the southwest. Almost all the displacement took place prior to batholithic intrusion, although granodiorite has been sheared adjacent to the fault by renewed movement. Lesser faults have offset the Salmonberry Mountain syncline and truncated an infold of limestone west of the lake. A fault in the open pit appears to have displaced the limestone-argillite contact about 200 feet.

The only economic mineral in the area is magnetite, and of seven occurrences described, only the Brynnor mine deposit is commercially significant. It comprises two irregular orebodies that more or less follow the down-buckled faulted contact between the lower limestone and the argillite. The upper orebody, west of the fault, has been mined by open-pit methods. The lower orebody, east of the fault, was partly developed for underground mining before the project was abandoned.

# CHAPTER I

# Introduction

In this report the Kennedy Lake area covers a land area of about 27 square miles around the main southern part of Kennedy Lake, on the west coast of Vancouver Island (*see* Fig. 1). The Brynnor Mines Limited iron mine is in the southeast part of the area. The village of Ucluelet is 4 miles to the south, the resort of Long Beach is 3 miles west, and the village of Tofino is 14 miles to the northwest.

Bedrock in the area consists mainly of volcanic, sedimentary, and batholithic intrusive rocks of Early Mesozoic age. Rocks of this age and similar type underlie most of the northern and western parts of Vancouver Island, and bands of the volcanic and sedimentary rocks have been traced southeastward as far as Cowichan Lake (Fyles, 1955, pp. 19–25). The rocks are described at some length from the Zeballos-Nimpkish area (Hoadley, 1953), where the volcanic-sedimentary sequence was divided into the Karmutsen Group at the base, the Quatsino Formation in the middle, and the Bonanza Group at the top. Where the base is exposed,

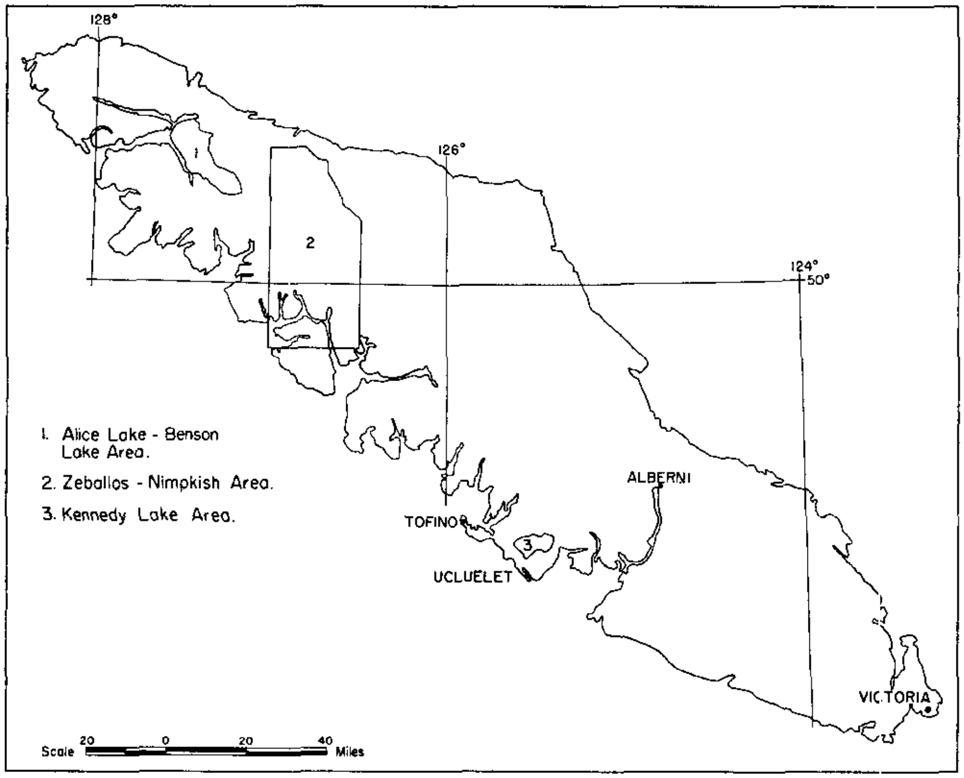


Fig. 1. Index map of Vancouver Island.

in the central and southern part of Vancouver Island, the Karmutsen Group overlies sedimentary and volcanic rocks of Permo-Carboniferous age (*see* Gunning, 1930, pp. 59–60; Fyles, 1955, pp. 18–19; Yole, 1963). Along the eastern part of the Island, the volcanic, sedimentary, and batholithic intrusive rocks are unconformably overlain by Cretaceous sedimentary rocks. Along the extreme west coast they are overlain by scattered patches of Oligocene sedimentary rocks, and in the Kyuquot-Esperanza area the Bonanza Group is apparently conformably overlain by upper Lower Jurassic sedimentary rocks (Jeletzky, 1954, p. 13). The structural trend throughout most of Vancouver Island is northwest, but in the Kennedy Lake area it is northeast to east.

The assemblage of Lower Mesozoic rocks on Vancouver Island is of economic importance for its contained deposits of magnetite and copper minerals. To the end of 1966, a total of 9,730,000 tons of iron concentrates and more than 63,000,000 pounds of copper had been produced from these deposits. The Brynnor mine in the Kennedy Lake area contributed 3,060,000 tons of iron concentrates to the total. Copper deposits also occur in older and younger rocks, but the magnetite deposits of Vancouver Island are almost all associated with the Quatsino Formation and with intrusions of intermediate composition (Eastwood, 1965, pp. 130–131), which are of Jurassic age where dated.

## TOPOGRAPHY

The Kennedy Lake area includes the southern part of Kennedy Lake, part of a narrow coastal plain, a relatively broad valley (here termed the Draw Valley), and detached and semi-detached spurs of the Vancouver Island Ranges.

Kennedy Lake is one of the two largest lakes on Vancouver Island, having an area of 24 square miles. It is roughly horseshoe-shaped, with the arms extending to the north and northeast. The north arm, called Clayoquot Arm, is connected with the main part of the lake only by a narrow channel and lies outside the area of this report. The northeast arm merges with the main part of the lake, but differs in character. The main part of the lake, at the base of the horseshoe, is broad and open, containing no islands or, as far as is known, reefs, except near shore. The shoreline in a broad way is smooth and regular. The northeast arm, on the other hand, is interrupted by two large islands, Laylee and Rocky, many small islands, and several large peninsulas. Random soundings by the Fish and Wildlife Branch indicate that much of the lake is no deeper than 230 feet, but that the northeast arm is locally as deep as 500 feet. The mean surface is 22 feet above mean sea-level; therefore, most of the lake basin is below sea-level.

The area between the arms of the lake in this report is referred to as the north peninsula. Most of it is a high mountain ridge, but toward the south end a transverse valley containing Angora Lake isolates a composite rocky hill on the southeast and a relatively low-lying area on the southwest.

The area between Kennedy Lake and the Pacific Ocean, and including the southwest corner of the north peninsula, is a local widening of the Estevan Coastal Plain (Holland, 1964, p. 32). A narrow extension of the coastal plain continues along the south side of the lake to the northwest corner of Mount Dawley. This coastal plain is an area of sands, gravels, and other unconsolidated materials, lying

Generally below 200 feet elevation, through which project scattered hills of bedrock. The highest of these hills* included in the map-area rises 700 feet from the west shore of the lake; from across the lake it appears beehive-shaped.

An irregular group of low timbered mountains rises abruptly east and south from the coastal plain and south from the lake. The higher part of the north section of this group may be very crudely described as a Y-shaped ridge, with summits at the points and fork of the Y. The summit at the northwest point (elevation 2,150 feet) has been named Salmonberry Mountain, and the summit at the northeast point (elevation 2,340 feet) Mount Dawley. They are separated by the deep valley of a small creek flowing into Kennedy Lake. Salmonberry Mountain is separated from a northwest ridge of Mount Frederick to the south by the deep valley of a somewhat larger creek, which turns abruptly north on reaching the coastal plain and also flows into Kennedy Lake. On the northeast and east, Mount Dawley slopes less steeply and more irregularly down to the Draw Valley.

The Draw Valley separates this mountain group from high country to the east. It extends southeast from Kennedy Lake to the mine, thence south to Maggie Lake, at the south end of which it merges with a narrow strip of coastal plain along the northwest shore of Barkley Sound. The valley is floored with thick deposits of sand and gravel, which near Kennedy Lake assume the form of a river delta, deposited at a time when the direction of drainage was reversed. The present drainage is predominantly southeast and south, and only minor creeks flow to Kennedy Lake through and beside the delta. Draw Creek enters the valley from the north about a mile from Kennedy Lake and flows to Maggie Lake, which drains via the Maggie River to Barkley Sound. Between the mine and the delta the valley configuration is complicated by two bedrock ridges, elongated parallel to the valley walls. There are thus three drainage divides, at about 350 feet elevation on either side of the northerly ridge and about 550 feet to the southwest of the southerly ridge. Including these two ridges and the covered, gentle, lower sideslopes farther south, the valley generally has a width of 1 mile, narrowing to a half-mile along the north part of Maggie Lake.

Between the south part of the Draw Valley and Toquart Bay to the east, a large north-trending ridge rises generally to about 2,000 feet and culminates in Mount Redford, of about 2,410 feet elevation, at the north end. A broad saddle at about 800 feet elevation separates this ridge from Draw Mountain to the north. Redford Creek originates in this saddle and flows west and south to join Draw Creek at the mine. Draw Mountain is bounded on the east by a broad basin that extends north from Toquart Bay, and by the narrow, deep valley of a small creek that flows south before turning east to flow into the basin. On the north it is separated from a higher peak at the southwest end of the Mackenzie Range by a broader valley trending northeast to east and having a saddle at just under 1,500 feet elevation. On the west it rises steeply from a south-sloping upland area. The summit of Draw Mountain is a narrow north-trending ridge which rises to just over 2,600 feet elevation. The upland rises gradually from the north side of the Draw Valley to elevations of 1,100 to 1,200 feet, where it merges with the valley northwest of Draw Mountain and is separated from the steep slope down to Kennedy

* Technically it is termed a huerfano (pronounced waré-fan-o), defined as a projection of older rock through younger, flat-lying sediments. It is a topographic feature homologous with nunatak and kipuka.

Lake by a ridge of 1,600 feet elevation. Draw Lake occupies the southwest part of the valley, and Draw Creek drains south to the Draw Valley, incised about 200 feet into the upland.

## CLIMATE AND VEGETATION

The area has a high annual precipitation, which falls mostly as rain and mostly in the winter months. Precipitation records kept by the mine staff since October, 1960, show that the total varies widely from year to year but exceeds 200 inches in most years. Snow seldom falls below 1,000 feet elevation. In the summer months the periods of rain are shorter and less frequent than in the winter.

In the summer, in the intervals between rain, the area is frequently blanketed by fog, and the vegetation remains dripping wet for a week or more. A typical sequence begins with a light ground mist spreading over the coastal plain at sunset. The ground mist is dispersed an hour or two after sunrise, but on successive evenings it grows increasingly thick, it envelops higher and higher ground, and it takes correspondingly longer and longer each morning to disperse. It also re-forms earlier and earlier. On the third day the intensity and duration of sunlight are insufficient to dry the vegetation. Frequently, by the fifth day the sun is visible for only about half an hour around 4 p.m. At this stage the deep fog begins to precipitate a fine drizzle, which gradually increases until a rainstorm crosses the area.

The vegetation is correspondingly prolific. Where not cut over, most of the area is thickly timbered with large cedar, hemlock, and fir. Locally the timber is scrubby, as in swampy areas of the coastal plain, on the upland south of Draw Lake, and on some large outcrop areas of Karmutsen volcanic rocks. A strip along the south side of Kennedy Lake was logged in the early fifties, and considerable areas of the coastal plain were logged in succeeding years. The Draw Valley and parts of the Redford Creek valley were logged in 1960–63. In the earlier logging, slash was not burned, and these areas are now exceedingly tangled.

The more profuse kinds of underbrush include salal, salmonberry, blueberry, red and purple huckleberry, and evergreen huckleberry. This last shrub grows most thickly on the rocky hills of the coastal plain, where the stiff, tough trunks rise 3 to 5 feet then curve almost back to the ground, creating an almost impenetrable tangle. Alder infests old logging-roads. Deadfall and underbrush are thickest on north-facing slopes, particularly over limestone areas, and thinnest on south-facing slopes. The underbrush decreases slightly from west to east and with increasing elevation.

## ACCESS

The Kennedy highway passes through the area, connecting Alberni and the Island highway system with Tofino and Ucluelet on the west coast. Several private roads of MacMillan Bloedel Limited lead off this highway and provide access to other parts of the area. One such road extends up the west side of Kennedy Lake, crosses the narrow channel leading to Clayoquot Arm, and continues around the end of the north peninsula. Another passes southwest along the base of Salmonberry Mountain. A third leads south to the mine and continues down the Draw Valley to Maggie Lake. A branch of this road extends up the Redford Creek valley and onto the lower south slope of Draw Mountain. A private road of Brynnor

Mines Limited extends from the mine down the Draw Valley and around the south end of the high ridge to the mill and deep-sea loading-dock on Toquart Bay. Many short branches lead off the main logging-roads. The older ones are impassable for wheeled vehicles, but most of them can be travelled on foot.

## EXPLORATION AND MINING

Previous geological work was of a reconnaissance nature. Webster and Haycock in 1902 and Dolmage in 1920 cruised along the sea coast and the shores of Kennedy Lake. The Noranda staff compiled a geological sketch of the area from scattered observations made by themselves and by prospectors working for the company. There was considerable prospecting between 1897 and 1918 to the north and northeast of the map-area, and some development work was done on several gold-bearing quartz veins. Since these showings were reached by boating along Kennedy Lake, it is reasonable to suppose that a considerable part of the map-area was prospected at the same time, but the only positive indication of such work that has been recorded is the report of a magnetic anomaly on Draw Creek (then known as Magnetic Creek).

This magnetic anomaly was investigated by Herbert Carmichael, Provincial Assayer, in 1902, and by Einar Lindeman of the Dominion Mines Branch in 1908, but no magnetite was found. Early in 1960, E. M. Chase, by dip-needle, found a strong magnetic anomaly on Draw Creek and located covering claims. Western Ferric Ores Ltd. diamond drilled 1,184 feet in six holes and ran additional dip-needle traverses, then sold its interest in the property to Noranda Exploration Company, Limited, in May, 1960. The property was transferred to the parent company, Noranda Mines, Limited, in 1961, and to another wholly owned subsidiary, Brynnor Mines Limited, the present owner, in 1962. A magnetometer survey was made, and about 40,000 feet of additional diamond drilling was done. The overburden and waste rock were stripped from one orebody by a contractor, Kie Mine Co. Ltd., in 1961–62, and Brynnor Mines Limited proceeded to mine the orebody by open-pit methods. A deeper orebody, southeast of the open-pit orebody, had been indicated by the diamond drilling, and underground development was begun in 1963. A shaft was sunk to the south of the open pit, and crosscuts from it on two levels reached the orebody in 1965. This development was greatly hampered by exceedingly heavy inflows of water. In 1967 the company announced that this underground operation was being abandoned.

## FIELD WORK AND ACKNOWLEDGMENTS

The writer spent a total of seven months in 1961–63 studying the Brynnor deposit and mapping the Kennedy Lake area. An additional week was spent in the area in 1965, principally examining mineralization in the underground section of the Brynnor mine. One-quarter square mile in and around the open pit was plane-tabled at 100 feet to the inch, and 9,100 feet of selected diamond-drill core was logged. Areal mapping at half-mile to the inch occupied two months in 1962 and three and one-half months in 1963. It was undertaken to clarify the relationship of the deposit to the rocks and structures, to provide a framework for further mineral exploration, and to correlate the rocks with formations in other parts of Vancouver Island. Department of Lands, Forests, and Water Resources manuscript maps at half-mile to the inch were used as a base. Where the geology was complex, all outcrops were studied and plotting was done in the maximum detail possible at this scale. Most geologic features were plotted directly on the base with the aid of altimeter readings and aerial photographs. The variation in barometric pressure during a working-day was generally less than the equivalent of 50 feet of elevation, or half the contour interval of the base, and adjustments were usually unnecessary. Adjusted photo-centre laydowns were not available, and radial plotting from aerial photographs was avoided wherever possible, but in the flat coastal plain several centres had to be approximated for this purpose. The gabbro stock west of the lake was outlined on aerial photographs, and the outline was transferred to the base with a map-o-graph. Compass resection was rarely possible because of the dense vegetation. Northeast of the mine some tape-and-compass and pace-and-compass mapping was done and plotted at 500 feet to the inch.

R. W. Yole, then a graduate student at the University of British Columbia, and A. Sutherland Brown, of the Department, visited the writer in the field in 1962 and 1963 and greatly assisted the correlation of the volcanic and sedimentary rocks with the Zeballos-Nimpkish section. One fossil specimen was examined by J. A. Jeletzky, of the Geological Survey of Canada, and a fossil collection was identified by W. R. Danner, of the University of British Columbia. The writer was assisted in the field by J. F. Fairley in 1961, F. M. van Netten in 1962, and M. M. Schuler in 1963 and 1965.

The work was facilitated considerably by the co-operation and courtesies extended by the Noranda group of companies, Kie Mine Co. Ltd., and MacMillan Bloedel Limited. The private mining and logging roads were used freely with the permission of the owners. The writer benefited from ready access to mine maps and from much useful discussion with W. I. Nelson, Jr., the mine geologist. The company's geological sketch-map was of considerable help in planning the areal mapping. Board was obtained first from Kie Mine Co. Ltd., then from Brynnor Mines Limited. Kie Mine Co. Ltd. supplied free use of a trailer in 1962, and Brynnor supplied accommodation in 1963.

## BIBLIOGRAPHY

Badgley, P. C. (1965): Structural and Tectonic Principles, *Harper and Row*, New York.

Bancroft, M. F. (1937): *Geol. Surv., Canada,* Mem. 204, pp. 3–13.

Billings, M. P. (1937): *Geol. Soc. Amer.,* Bull., Vol. 48, p. 537.

——— (1942): Structural Geology, *Prentice Hall,* New York.

——— (1945): *Am. Jour. Sci.,* Vol. 243A (Daly Volume), pp. 40–68.

Buddington, A. F. (1959): *Geol. Soc. Amer.,* Bull., Vol. 70, pp. 671–747.

Carlisle, Donald (1963): *Jour. Geol.,* Vol. 71, pp. 48–71.

Dolmage, Victor (1918): *Geol. Surv., Canada,* Sum. Rept., Pt. B, pp. 30–38.

——— (1920): *Geol. Surv., Canada,* Sum. Rept., Pt. A, pp. 12–22.

Eastwood, G. E. P. (1962): *Minister of Mines and Pet. Res., B.C.,* Ann. Rept., pp. 111–122.

Eastwood, G. E. P. (1965): *Ec. Geol.*, Vol. 60, pp. 124–148.
Fyles, James T. (1955): *B.C. Dept. of Mines*, Bull. 37.
Gault, H. R. (1945): *Geol. Soc. Amer.*, Bull., Vol. 56, pp. 210–244.
Gilluly, James (1966): *Am. Jour. Sci.*, Vol. 264, pp. 97–111.
Gunning, H. C. (1929): *Geol. Surv., Canada,* Sum. Rept., Pt. A, pp. 99–109.
——— (1930): *Geol. Surv., Canada,* Sum. Rept., Pt. A, pp. 58–65.
——— (1931): *Geol. Surv., Canada,* Sum. Rept., Pt. A, pp. 23–25.
——— (1932): *Geol. Surv., Canada,* Sum. Rept., Pt. A II, pp. 33–35.
Haycock, Ernest (1902): *Geol. Surv., Canada,* Ann. Rept., Vol. XV, Pt. A, pp. 81–90.
Hoadley, J. W. (1953): *Geol. Surv., Canada,* Mem. 272.
Holland, Stuart S. (1964): *B.C. Dept. of Mines and Pet. Res.*, Bull. 48.
Holser, W. T., and Schneer, C. J. (1961): *Geol. Soc. Amer.*, Bull., Vol. 76, pp. 369–386.
Jeffery, W. G. (1962): Alice Lake-Benson Lake Area, *B.C. Dept. of Mines and Pet. Res.*, Preliminary Map.
Jeletzky, J. A. (1954): *Geol. Surv., Canada,* Paper 53-17.
King, P. B. (1955): *Geol. Soc. Amer.*, Special Paper 62, pp. 723–739.
Larsen, E. S. (1945): *Am. Jour. Sci.*, Vol. 243A (Daly Volume), pp. 399–416.
Lindeman, Einar (1910): Iron Ore Deposits of Vancouver and Texada Islands, British Columbia, *Mines Branch, Ottawa,* Publ. No. 47, p. 16.
*Minister of Mines, B.C.*, Ann. Rept., 1902, p. 210.
*Minister of Mines and Pet. Res., B.C.*, Ann. Repts., 1960, pp. 108–110; 1961, pp. 104–110; 1962, pp. 122–124; 1963, pp. 117–121; 1964, pp. 167–168; 1965, pp. 236–238.
Muller, J. E. (1966): *Geol. Surv., Canada,* Paper 66-1, pp. 74–77.
Read, H. H. (1949): *Quar. Jour. Geol. Soc., London,* Vol. 105, pp. 117–118.
Tozer, E. T. (1961): *Geol. Surv., Canada,* Paper 61-6.
White, W. H. (1959): *Amer. Assoc. Pet. Geol.*, Bull., Vol. 43, pp. 60–100.
——— (1966): Summary of Tectonic History, *C.I.M.M.*, Special Vol. No. 8, pp. 185–189.
Williams, C. R., and Billings, M. P. (1938): *Geol. Soc. Amer.*, Bull., Vol. 49, pp. 1011–1042.
Yole, R. W. (1963): *Can. Pet. Geol.*, Bull., Vol. 11, pp. 138–149.
Young, G. A., and Uglow, W. L. (1926): The Iron Ores of Canada, British Columbia and Yukon, *Geol. Surv., Canada,* Ec. Geol. Series No. 3, Vol. 1, pp. 155–158.

# CHAPTER II

# General Geology

The sequence of rocks in the area is shown in the following Table of Formations. The most widespread bedrocks are the batholithic rocks, which underlie most of the southeast half of the area, and the Karmutsen volcanic rocks, which outcrop extensively around the main part of Kennedy Lake. From scattered observations outside the area, it appears that batholithic rocks extend southeast to Barkley Sound and Toquart Bay, and the Karmutsen Group extends for some miles to the north and northeast. The batholithic rocks contain many small inclusions of Karmutsen volcanic rock and Quatsino limestone, and one very large inclusion or roof pendant of Quatsino limestone and argillite. This pendant extends almost 2 miles north-northeast from the Brynnor mine, and is conveniently referred to as the mine belt. A larger belt of Quatsino rocks extends generally along the south shore of Kennedy Lake, from a point due east of Laylee Island over Salmonberry Mountain to the extreme northwest corner of Mount Frederick, and is referred to as the lakeshore belt.

In addition to the units listed in the table, folded clastic sediments of uncertain age are exposed along the Pacific shore. They lie outside the area proper, but are shown in Figure 3.

## KARMUTSEN GROUP (1, 1*a*)

### Distribution

Rocks assigned to the Karmutsen Group constitute most of the bedrock along the west, north, and east sides of Kennedy Lake and occur in several small patches southwest of Draw Mountain. The exposures are large and small outcrop areas which are isolated from each other mainly by overburden and by the lake. The largest outcrop areas included within the map-area are (1) a strip along the east end of the lake from the delta to the base of the long peninsula, (2) Laylee Island, (3) the southeast part of the north peninsula, (4) an area at the west end of the lake including the beehive-shaped hill and extending south to the west bay of the lake, (5) a low ragged hill lying due west of the west bay, and (6) a rectangular area astride the highway, extending from the south side of the lake southeast almost to the creek that flows north along the west foot of Salmonberry Mountain. Within the outcrop areas the rock is generally well exposed. The individual exposures include sloping and sub-horizontal rock surfaces as well as small cliffs. Large cliffs, more than a few tens of feet in height, are uncommon, and steep slopes are generally stepped.

The Karmutsen rocks probably are more or less continuous under overburden and water between the outcrop areas around the main part of the lake; that is, the discontinuity of exposure is thought to result principally from Quaternary or Late

*Table I.—Table of Formations*

| Age | Unit | | Map Unit No. | Lithology |
|---|---|---|---|---|
| Quaternary. | Surficial deposits. | | 13 | Till; alluvial gravel, sand, silt, clay; local pebbly clay. |
| | | Unconformity. | | |
| ? | Kennedy Intrusions. | | 12 | Basalt and gabbro dykes and stock. |
| | | Probable intrusive contact. | | |
| Lower Cretaceous. | Younger Porphyry. | | 11 | Light-coloured basalt porphyry dykes. |
| | | Relations unknown. | | |
| ? | Minor Felsitic Intrusions. | | 10 | Felsite, aplite, and fine-grained granodiorite, in dykes and small masses. |
| | | Intrusive contact. | | |
| Middle Jurassic. | Batholithic Intrusions. | | 9 | Granodiorite, quartz monzonite, and tonalite. |
| | | | | Contact intrusive to gradational. |
| | | | 8 | Diorite, quarz-bearing diorite. |
| | | Intrusive contact. | | |
| Lower Jurassic(?). | Older Porphyry. | | 7 | Dark feldspar porphyry dykes and small masses. |
| | | Relations unknown. | | |
| Lower Jurassic or Upper Triassic(?). | Andesite Intrusions. | | 6 | Andesite dykes and small stocks. |
| | | Relations unknown. | | |
| Lower Jurassic or Upper Triassic. | Bonanza Group(?). | | 5 | Tuffaceous andesite. |
| | | Apparent conformity. | | |
| Upper Triassic. | Quatsino Formation. | Upper Member. | 4 | Massive-bedded grey limestone. |
| | | Middle Member. | 3 | Argillite and tuffaceous argillite, mostly banded. |
| | | Lower Member. | 2 | White to grey limestone, thin to thick bedded. |
| | | Apparent conformity. | | |
| | Karmutsen Group. | | 1<br>1*a* | Amygdaloidal and massive andesite and basalt, locally containing small pillows.<br>Agglomerate and breccia with some pillows. |

Tertiary sculpturing and sedimentation rather than from interruption of the Karmutsen by other bedrocks. Continuity beneath overburden was demonstrated in one instance by two diamond-drill holes put down through the delta. The prevalence of Karmutsen rocks around the main part of the lake and the apparent structural pattern indicate that large areas of intrusive and Quatsino rocks are not to be expected beneath the lake.

The small outcrops of Karmutsen-like rock between Draw Mountain and the apex of the delta are, on the other hand, demonstrably inclusions in the batholithic rocks. Most of them are only a few feet or a few tens of feet across, and only two are large enough to show on Figure 2. They are discussed further with the batholithic rocks.

## Lithology

The Karmutsen rocks are dark greyish-green and locally greenish-black in colour. They weather to a medium grey or greyish-green, and on some restricted surfaces to a light grey or dirty cream colour. They generally appear much darker than the batholithic rocks and the Quatsino rocks.

A considerable part, possibly one-third, of the group exposed within the area lacks distinctive macroscopic primary textures and structures, and appears in outcrop and hand specimen as a massive fine-grained greyish-green rock. The matrix of amygdaloidal and porphyritic rock appears identical with the massive rock.

The greater part, possibly two-thirds, of the Karmutsen Group within the area is more or less amygdaloidal and porphyritic. The phenocrysts are single crystals or aggregates of a few relatively large crystals of plagioclase. The amygdules are of two kinds. One kind consists almost entirely of chlorite and is 4 to 5 millimetres in greatest dimension. It is oval, teardrop-shaped, or irregular in form. The other kind of amygdule is a tiny white ovoid, 1 to 1½ millimetres in greatest dimension, which in thin-section was seen to consist of fine-grained quartz and feldspar.

The macroscopic appearance of uniformity in the massive rock and the matrix of the amygdaloidal rock is dispelled under the microscope. Of four specimens taken at random along the highway east of the lake and one from drill core from beneath the delta, one proved to be almost medium grained, whereas the other four were fine to very fine. A specimen from 250 feet north of the delta has a finely pelletal structure, on which a felt of actinolite needles has been superimposed. The pellets are of at least three different types and show a crude stratification; the rock is probably a volcanic sandstone. The other four specimens range from finely granitoid to felted in texture. The principal primary minerals in three specimens are plagioclase and hornblende. Two other specimens contain abundant actinolite and but sparing hornblende. In three specimens, magnetite constitutes about 8 per cent and appears to be a normal accessory mineral, but in the two other specimens it is a major constituent. It constitutes about 18 per cent of the drill-core specimen, and forms lath-shaped grains, irregular blebs and clusters, and rims around large and small areas of chlorite. It seems likely that much of this magnetite has formed during the breakdown of hornblende, and possibly other ferromagnesian minerals, to chlorite. In a specimen from a contact with a granodiorite dyke, magnetite constitutes about 15 per cent of the rock, and clearly much of it has been introduced. Most of the specimens contain a little chlorite derived from alteration of hornblende, and some also contain a little clinozoisite and epidote. Quartz veinlets occur in the high-magnetite specimens. Several specimens are traversed by narrow crush zones, and one is extensively crushed.

The plagioclase composition was determined by the Michel-Levy method, and the true anorthite contents are probably somewhat higher than the values obtained. Even with some allowance for failure to find the highest extinction angle, however, the plagioclase in three specimens is clearly andesine. Only two specimens contain labradorite. It may be significant that these two were taken from horizons that appear to be higher than those yielding the other three specimens.

Pillow and pillow-like structures have been found at several places in the Karmutsen rocks. Along the highway east of the lake a few curving bands of epidote suggest rinds of incompletely formed pillows. About one-third of the way up the east shore of Laylee Island, epidote-rich bodies comprise scattered angular blocks, 1 to 6 inches across, and roughly elliptical bodies, a foot or more long, in a zone not more than 200 feet wide. Scattered, poorly formed pillows occur at the north end of the southeast cape of the north peninsula and in the middle of the south end of the peninsula. Crowded well-defined circular bodies, 4 to 8 inches in diameter, are exposed on the summit of the hill south of Angora Lake and on the west base of this hill, at the contact with extensive overburden, where the band is about 50 feet wide. This band was not followed between the two observations, but it is similar and distinctive at both points, and the inferred strike accords well with the general strike of the rocks. A similar band is exposed on the east end of the beehive-shaped hill, at about 100 feet above Kennedy Lake.

A fragmental zone, shown as unit 1*a* on Figure 2, is exposed on the north half of Laylee Island, on the southeast cape of the north peninsula, and on a small island to the southwest. On Laylee Island two bands containing abundant well-defined fragments are separated and flanked by rock showing scattered obscure structures that may be fragments. The well-defined fragments are from one-quarter to 3 inches across and are mostly angular. They weather dark greyish-green or greenish-black, whereas the matrix tends to weather medium green. They also tend to weather in relief, forming knobbly surfaces. The obscure structures do not differ from the matrix in colour, and are recognized only from their weathering in relief. A few can be related to small close-spaced intersecting joints, but most of them give no indication of their origin. They may or may not be primary volcanic fragments. As mapped, the zone includes the rock showing the obscure structures, and its outcrop belt on Laylee Island is 2,000 feet wide. The bands of well-defined breccia are each about 300 feet wide. On the southeast cape of the north peninsula, well-defined fragments are present across the full width of exposure of about 1,000 feet, and two distinct bands are not evident. The small island to the southwest consists entirely of well-defined breccia.

These pillow and fragment-bearing rocks to some extent resemble the pillow breccias described and figured by Carlisle (1963). The rock on Laylee Island containing angular blocks and roughly elliptical bodies would appear to be transitional between his isolated-pillow breccia and his broken-pillow breccia, and the rock on the north peninsula containing scattered poorly formed pillows may be isolated-pillow breccia. The obscure fragment-like structures in the rock adjoining the well-defined breccia perhaps may be glass clots. The well-defined breccia, comprising abundant fragments and subordinate matrix, is not typical of his broken-pillow breccia and may have had a different origin.

The two bands of well-defined breccia on Laylee Island and the single broad band on the southeast cape of the north peninsula would appear to outline a fold. If the whole fragmental zone, as mapped, is taken to be broken-pillow breccia, then, according to the sequence established by Carlisle, it should overlie pillow-bearing rocks on its flanks, and the fold would be a syncline, apparently plunging northeast. This interpretation is supported by exposures on the southeast cape, where pillow-bearing rocks at the north end appear to grade southward through vaguely fragmental rocks to well-defined breccia. On Laylee Island, however, the pillow-bearing and pillow-free breccias are separated by some 1,500 feet of amygdaloidal lava, and evidently belong to different sequences. It is possible that several partial sequences are represented, and that the pillow-bearing rocks on the southeast cape actually overlie the pillow-free breccia. The data collected do not permit a conclusion as to the sequence of the rocks and the nature of the fold.

Bedded tuffs have not been recognized in the Karmutsen Group in the Kennedy Lake area. A thinly banded rock north of the beehive-shaped hill appears in thin-section to have been produced from massive lava by shearing and alteration.

Secondary structures include common fractures, scattered veins and lenses of epidote, and rather rare veinlets of quartz and carbonate. Andesite dykes have not been positively identified, although some presumably should cut the group, considering that they are common in the overlying Quatsino limestone. They are so similar to the massive Karmutsen in appearance that they could be distinguished only on exceptionally fresh, clean surfaces. A few scattered basalt and gabbro bodies belonging to the Kennedy Intrusions have been identified in the Karmutsen rocks, and more may be present; narrow dykes are as fine grained as the massive Karmutsen and closely resemble it.

### Internal and External Relations

The internal stratigraphy of the group has not been worked out, although it probably could be established if enough time were devoted to it. Faulting and the isolation of the outcrop areas by overburden and lake have chopped the group into a number of blocks whose mutual relations are poorly known. Relatively little time was spent examining Karmutsen exposures, since the principal object was a search for limestone.

In general, the uppermost part of the group appears to be largely massive, although it contains some probable volcanic sandstone. It is underlain by a probably thick section of amygdaloidal and porphyritic lavas containing a few widely scattered and poorly formed pillows. There are probably several additional massive members lower in the column. Three fairly distinctive members occur at an unknown depth below the top of the group: Thin member of closely packed small pillows; somewhat thicker member containing larger pillows and fairly large fragments of pillows; fragmental member, containing broken-pillow breccia of relatively small fragments (unit 1*a*). These members are separated by several hundred feet of predominantly amygdaloidal lava. They are listed from youngest to oldest if the Laylee Island fold is an anticline, or from oldest to youngest if the fold is a syncline. The base of the group is not exposed within the map-area.

The group is apparently overlain by limestone of the Quatsino Formation. Through the lakeshore belt, scattered bedding in the limestone dips uniformly away from the contact. On Salmonberry Mountain this limestone is overlain by Quatsino argillite in a syncline, and the beds are concluded to be right side up. The actual contact is exposed only in a highway road cut just south of the delta, where it is in fact a transitional zone about 5 feet thick, of light to medium green, somewhat sheared rock. Northeast of the delta, exposures of the two rocks are everywhere separated by at least a few feet of overburden. In the highway cut at the north edge of the area, the limestone lacks bedding and is intruded by a great many andesite dykes, so that it is not clear whether the final contact is with Karmutsen volcanics or with another dyke. On the north peninsula the contacts are extensively covered, and west of the lake they are either covered or are fault contacts. On the south slope of Draw Mountain a small outcrop of Karmutsen-like rocks lies close to the axis of the mine belt anticline and, therefore, presumably underlies Quatsino limestone exposed a short distance to the south.

In the southwest and northeast parts of the area, the Karmutsen rocks are intruded by the main mass of the batholithic rocks. In the northeast the intrusion is peripheral, but in the southwest a considerable block of Karmutsen rocks evidently has been obliterated. Scattered dykes of diorite and granodiorite intrude the Karmutsen rocks, and are especially common in exposures east of the lake.

## QUATSINO FORMATION (2, 3, 4)

### Distribution

Limestones, argillite, and tuffaceous argillite assigned to the Quatsino Formation constitute the lakeshore and mine belts. The lakeshore belt lies between Karmutsen rocks on the northwest and batholithic rocks on the southeast, and from a point a mile northeast of the delta extends southwest for 6 miles to the extreme northwest corner of Mount Frederick. In the northeast it is pinched out by encroachment of granodiorite. In the southwest it is truncated by a fault and engulfed by the batholith. The mine belt extends for almost 2 miles from a point a short distance south of the Brynnor mine to the lower south slope of Draw Mountain. It is flanked by diorite and is almost bisected by an irregular tongue of granodiorite. It passes under cover at both ends, but diorite appears beyond the cover and has evidently engulfed the Quatsino rocks.

Several limestone inclusions occur in the batholithic rocks near the west margin of the mine belt and to the north of the lakeshore belt. Another occurs almost midway between the belts, on an easterly tributary of upper Draw Creek. Yet another occurs in the southwest part of the area, opposite the northwest foot of Mount Frederick. These inclusions range from about 50 to several hundred feet across. They add little to knowledge of the Quatsino Formation, but they are significant for the clues they offer concerning the course of batholithic intrusion and the structural pattern of the area.

The remaining outcrops of limestone in the map-area comprise four small areas on the southwest part of the north peninsula and two small areas and one large area west of Kennedy Lake. They are tentatively correlated with Quatsino limestone solely because they are identical or closely similar lithologically. Contacts with Karmutsen rocks are mostly covered or are apparently faults. No fossils have been found in them. While it is conceivable that they are lenses in the Karmutsen Group, such as are known from other parts of Vancouver Island, the large outcrop area west of the lake is considerably larger than any known lens. Tentatively, most of these limestone areas are regarded as infolds of Quatsino limestone in the Karmutsen Group. One is evidently a fault slice.

The Quatsino limestone and argillite are moderately well exposed, but somewhat less so than the batholithic rocks. They generally do not show the tendency of the Karmutsen rocks to occur in large isolated outcrop areas, but rather form thickly scattered small outcrops. The limestone on the north peninsula and west of Kennedy Lake is an exception, forming isolated outcrop areas that are mostly small. The individual outcrops are commonly small cliffs. Flat surfaces of limestone and argillite are uncommon except in creek beds and along the south shore of Kennedy Lake. Some limestone exposures comprise the upper few feet of the walls of sink-holes. Limestone inclusions in batholithic rocks rarely weather in positive relief; instead, they are commonly found adhering to small bluff faces and in gullies that cross both limestone and intrusive rock.

### Lithology

The Quatsino Formation in the Kennedy Lake area comprises lower and upper limestone members (units 2 and 4) and an intervening member (unit 3) of banded argillite. Unit 4 is restricted to Salmonberry Mountain, the extreme northwest corner of Mount Frederick, and two small outcrops on the east edge of the mine belt. Unit 3 is also restricted to Salmonberry Mountain in the lakeshore belt, but occurs generally along the flanks of the mine belt, and may also occur at the north end of Draw Mountain. The contacts between members are gradational and have been placed arbitrarily at points where the two rock types constitute equal parts of the exposure. As thus defined, and on Salmonberry Mountain, the argillite member is 800 feet thick and the upper limestone is 350 feet thick. No complete uncomplicated section of the lower limestone has been found in the map-area. Exposures off the northwest corner of Salmonberry Mountain suggest that it is at least 2,000 feet thick. Exposures on the south slope of Draw Mountain suggest that it is there less than 1,500 feet thick, but the exposure is not good, and the structure of that section is not known in any detail.

The limestone of both upper and lower members varies from white to medium and dark grey and from coarse to medium grained. It has evidently been extensively recrystallized. Most outcrops give off a strong odour of hydrogen sulphide when struck with a hammer. An isolated small bluff of the upper limestone off the southwest tip of Salmonberry Mountain weathers to a distinctive dark bluish-grey. A similar weathering colour occurs on a small cliff of the lower limestone in the middle of the north segment of the mine belt. Predominantly, however, the limestones weather light buff or shades of grey. White limestone probably has resulted from bleaching during recrystallization and metamorphism, whereas most of the grey limestones would appear to have retained their original colour. There is no indication that any of the beds ever was black.

For the most part, the limestones are fairly pure. A few small rounded grains of quartz appear in most thin-sections. Pyrite occurs sporadically. Yellow grains that are probably ankerite were noted in a few places. Plates and nodules of brucite were found in the upper limestone close to where it is truncated by the batholith on the north slope of Salmonberry Mountain.

Bedding in the limestones as a rule is not evident. In the upper member, bedding-like structures are rarely seen. In the lower member, bedding-like structures are common in the lakeshore belt, and since they are generally consistent with each other and with the sedimentary contacts, most of them probably do represent bedding. The commonest structures are extensive fractures which weather to southeast-dipping cracks. Weathering patterns produce a crude banding, especially along the north face of Mount Dawley. Some bands are deeply etched in crude diamond patterns, whereas adjoining bands may be only slightly etched or smoothly weathered. The deeply etched bands are commonly cream or light buff in colour, whereas the smoothly weathered bands are commonly white or shades of grey. These features would suggest compositional differences, but none has been found in the thin-sections studied. The bands are commonly separated by the extensive fractures. Straight colour banding, in white and shades of grey, is common but can be identified as bedding only where confirmed by other features. Individual bands are rarely recognizable for more than 50 feet due to colour changes along the strike. The lateral colour changes are irregular in over-all pattern and are probably related to factors of metamorphism and recrystallization rather than to primary features; therefore, the banding itself may be in part related to recrystallization. On the shore of Kennedy Lake north of the Brynnor camp, the limestone contains thin bands of angular andesitic fragments which maintain uniform spacings and even outline a small shallow dragfold. The fragments range from nearly cubic blocks an inch across to plates 2 or 3 inches thick and a foot long. Probably they are broken tuff beds, the sheets representing bedding surfaces. Stylolitic partings occur here and there.

In the mine belt, bedding-like structures are less common in the lower limestone. In the open pit some light and dark banding was seen, but some of it was definitely not bedding. In at least one place, two sets of dark bands were seen to cross at a large angle, and possibly the thinner, blacker bands represent metamorphic segregation of impurities along old sheeting planes. In Redford Creek, near the east edge of the belt, flat-lying buff bands of diopside rock, 1 to 5 inches thick, weather in relief; they may or may not represent bedding.

The limestone on the north peninsula and west of Kennedy Lake is rather uniformly white to light grey, and is not as markedly and differentially etched as is the limestone on Mount Dawley. It does, however, show sparse bedding plane-like fractures and thin bands of andesitic fragments.

Solution features are common in the limestones. Etched surfaces have already been noted. Cliffs of smooth-weathering limestone are deeply fluted. The interflute ridges are normally rounded, but in parts of the upper limestone they are sharp, and in the lower limestone in places on Redford Creek they are greatly attenuated. Flat or gently sloping outcrops of limestone have been subject to considerable solution along steep joint planes, resulting in a series of deep, narrow trenches. Sink-holes occur here and there. On Salmonberry Mountain small creeks disappear and reappear, and a traverse at one elevation may cross a deep gully, whereas another traverse 300 feet higher or lower may be on a uniform slope.

The rocks of the middle member are hard and siliceous appearing, and in most exposures they are markedly banded. The bands are one-half to 3 inches thick and are white, cream, pale pink, pale to medium green, or light to dark grey in colour. In most exposures the lighter-coloured bands predominate, but a few grey bands are intermixed. In a few scattered exposures the rock is either uniformly dark grey or it comprises medium- and dark-grey bands. On Salmonberry

Mountain and on upper Redford Creek, above the branch-road bridge, limestone beds are intercalated in the lower 30 feet of the member. The adjacent bands are strictly parallel with these limestone beds, and it is concluded that they also are beds. The banding fades near skarn, and the rock becomes massive and white to cream in colour.

The banding appears to be variously primary, unmasked, and secondary. A thin-section from the upper wall of the open pit revealed that a dark-grey band is exceedingly fine grained and is coloured by a black dust, whereas an adjacent light-grey band is only moderately fine grained and contains virtually no dark colouring matter. This differentiation is probably a primary sedimentary feature. Another thin-section from the open pit discloses that a light olive-green band is diopside rock, and that adjacent light-grey and pale-pink bands consist of felsic minerals, clinozoisite, and epidote. The source of the pink colour is not apparent. A thin-section of the massive white rock consists largely of feldspar that is considerably altered to sericite. Some patches of uniformly dark-grey rock in the southwest wall of the pit grade laterally to white, pale-pink, light-green, and light-grey bands. This banding would appear to have been produced by a combination of selective alteration and unveiling of primary banding by bleaching of the dark colouring matter. More generally, the predominance of lighter-coloured bands on the northwest slope of Salmonberry Mountain, where metamorphism should have been much weaker, and the presence of interbedded dark bands, would suggest that much of the banding is primary, and that only certain sections of the member ever were uniformly grey in colour.

The rock consists essentially of quartz, feldspar, and products of alteration of the feldspar. Most of the felsic grains are too small to identify, but the presence of abundant sericite in some thin-sections would indicate a high feldspar content. Most of the thin-sections contain a little carbonate, and in most exposures the rock will effervesce slightly with acid. Some thin-sections from the open pit contain scattered small and large grains and veinlets of clinozoisite, some scattered epidote, and a few grains of garnet and magnetite. These four minerals, together with the scattered bands of diopside, would appear to represent incipient development of skarn, peripheral to the main mass that is associated with the magnetite orebody.

Most of the felsic grains are fine to very fine, and all but the finest of these show some rounding. The rock would therefore appear to be a detrital sediment. However, some thin-sections contain scattered larger grains of feldspar, both rounded and sharply angular. These angular grains appear to be fragments of euhedral crystals, and thus may be volcanic ejecta. Some beds may thus be tuffaceous, and the apparently high feldspar content would suggest an igneous source rock, but the rock is essentially a detrital sediment, and not a tuff as previously reported. It is called argillite because most of the grains are clay sized and because it lacks the bedding fissility of shale and the cleavage of slate.

A banded rock at the north end of Draw Mountain appears in thin-section to be largely chert, into which a few rounded detrital grains have been carried. It is therefore not closely similar to the Quatsino argillite, and its correlation is provisional.

The argillite member grades down to the lower limestone with the appearance of increasing numbers of increasingly thick limestone beds. Toward the top of the member the argillite beds thicken and become uniformly white and increasingly calcareous, thus grading up to the upper limestone. The lower transition zone is about 50 feet thick, and the upper is about 20 feet.

### Relationships

The Quatsino Formation appears to be a conformable succession, with gradational contacts between its members, and no apparent break in sedimentation. It appears to overlie the Karmutsen Group abruptly. No Karmutsen fragments are incorporated in the basal Quatsino beds and probably there was little erosion of the Karmutsen prior to Quatsino deposition. The formation is overlain on Salmonberry Mountain by predominantly tuffaceous rocks that are provisionally assigned to the Bonanza Group. This contact also is sharp, but here also there is no evidence of erosion. The upper limestone maintains a constant thickness along the west and north slopes of the mountain.

The formation is intruded by dykes, sheets, and small stocks of andesite. The dykes and sheets are exceedingly common and rather uniformly distributed through the lower limestone, and in effect contribute to its gross lithology. They also intrude the argillite and upper limestone, but are generally less common there than in the lower limestone.

The Quatsino rocks are in part engulfed by the batholithic intrusions, but isolated dykes and sheets of diorite and granodiorite are uncommon in them. They are, however, intruded by offshoots of the batholith that are connected to it at surface. One such offshoot transects the lakeshore belt along the creek between Mount Dawley and Salmonberry Mountain. A second, highly irregular offshoot nearly bisects the mine belt.

The Quatsino rocks are also intruded by the Older and Younger Porphyries and by the Kennedy Intrusions. In the creek bed at the southwest tip of Salmonberry Mountain, blocks of the upper limestone are included in the Older Porphyry. In the Brynnor mine the tuffaceous argillite is intruded by dykes of the Younger Porphyry and the Kennedy Intrusions. West of Kennedy Lake the larger area of limestone is intruded by a gabbro stock of the Kennedy Intrusions.

### Age and Correlation

Recognizable fossils are rare in the Kennedy Lake area. The only point at which they were found in place is on the northwest corner of Salmonberry Mountain, in the lower third of the argillite member of the Quatsino Formation. Fossils collected from this locality in 1963 by Sutherland Brown and the writer were not well preserved, and were identified by W. R. Danner, of the University of British Columbia, only as *Halobia*. The fossil-bearing horizon is therefore Late Triassic and Early Norian or Karnian in age.

Correlation of the several remnants of the Quatsino Formation within the area is based on closely similar lithology and lithologic sequence. Correlation with the Quatsino Formation of north Vancouver Island is based on the presence of *Halobia* in the argillite member and on similarities in lithology and sequence. In the Benson Lake, Zeballos River, and Kennedy Lake areas, clean grey limestone rests directly on a thick pile of volcanic rocks that in the writer's experience, and from descriptions by Gunning, Hoadley, and Jeffery, are virtually identical in lithology. At a number of places on north Vancouver Island, the clean limestone grades up through argillaceous and carbonaceous limestone to argillite. In the Benson Lake area a few beds of clean limestone are intercalated in the dark limestones. The transition in the Kennedy Lake area from the lower limestone to the argillite member differs in that dark limestones are not present and the beds of clean limestone are intercalated in argillite, but the over-all pattern is similar. *Halobia* has been found in clean and argillaceous or carbonaceous limestone at several localities on north Vancouver Island, but, as far as the writer is aware, it has not there been found in overlying argillites. This would indicate, incidentally, that argillite sedimentation began somewhat earlier in the Kennedy Lake area. The main conclusion, however, is that the lower limestone is of approximately the same age as the Quatsino Formation and, considering its similar lithology and its place in a similar sequence, can be firmly correlated with it.

The argillite member would be correlated with the sedimentary division of the Bonanza Group were it not for the presence of the upper limestone above it. Lenses of limestone have been found in the Bonanza Group at a number of localities, but they are up in the volcanics, not in the argillite, and they are much thinner than the upper limestone of the Kennedy Lake area. If the argillite were assigned to the Bonanza Group, the upper limestone would also have to be assigned to it, and both units would have to be given formational names. It is felt that designation of new formations is not justified in view of the restricted preservation of the upper limestone in the Kennedy Lake area, the metamorphism of the rocks, and the scarcity of fossils. Also, it appears desirable to include all the clean limestone in one formation. The argillite and upper limestone are therefore assigned to the Quatsino Formation.

It is possible that mapping in nearby areas will show the upper limestone pinching out in Bonanza argillites. This is a not uncommon facies relationship, and stratigraphic procedures have been developed to deal with it, as by arbitrary cut-off. It is also possible that most of the rocks above the *Halobia*-bearing horizon may be Upper Norian in age, and hence time equivalents of Bonanza rocks on north Vancouver Island. Since rock units have to be defined on the basis of lithology, this should not invalidate assignment of the upper limestone to the Quatsino Formation.

### Quatsino-Bonanza Boundary

Dolmage (1918, p. 32) proposed the name " Quatsino limestone " for a band of limestone that he found on Rupert and Neroutsos Inlets of Quatsino Sound, and which he traced southeast to Benson Lake. Gunning correlated this limestone with limestone on Nimpkish Lake and River (1929, pp. 103, 105) and on Zeballos River (1932, p. 33) on lithological and faunal grounds. He proposed (1931, p. 23) " Bonanza group," for the overlying assemblage of sedimentary and volcanic rocks, with the following proviso: " If this group be later subdivided, the term Bonanza should be retained for that division lying directly above the Quatsino formation."

Both in its type area and in the Zeballos-Nimpkish area, the Quatsino limestone grades up through impure limestone to argillite in some places and is abruptly overlain by pyroclastics or flows in others. This has given rise to some confusion over the placing of the Quatsino-Bonanza contact. Gunning says (1932, p. 34): "As a general rule the top of the Quatsino formation must be taken at the horizon where tuffs or argillaceous to quartzitic sediments become so abundantly interbedded as to form the bulk of the formation, so that, towards the top of the Quatsino limestone up to 50 per cent of the formation may be tuffs and other sediments, nearly always in very thin, sharply defined beds." Hoadley used different criteria in different places for defining the Quatsino-Bonanza contact. He says (1953, p. 20): "In Zeballos map-area, the writer found that it was more convenient, for the purposes of field mapping, to consider as the top of the formation the horizon in the succession where the rocks change in character from dominantly impure limestone and argillite to predominantly tuffaceous rocks associated with an ever increasing number of volcanic flows." But also (1953, p. 22): "Field work by the writer in 1947–49 has shown that the lower part of the Bonanza group in Zeballos map-area is also sedimentary in character, and lithologically similar to that described by Gunning in the Nimpkish area." In mapping the type area of the Quatsino Formation, Jeffery (1962) placed the top at the top of clean crystalline limestone, and included all the argillite and impure limestone in the sedimentary part of the Bonanza Group. He demonstrated that the boundary between the sedimentary and volcanic parts of the Bonanza Group is a facies boundary, lying at different stratigraphic horizons at different places, and that northwest of Victoria Lake volcanic rocks separate the sedimentary part of the group from Quatsino limestone.

Jeffery conceives (personal communication) that the top of the clean limestone was in part an undulating surface with no sedimentation on the higher areas and accumulation of impure limestone and argillite in shallow basins. In part there may have been no break in deposition. Jeffery concurs with the writer's concept of a gradually changing sedimentation punctuated by massive vulcanism that was initially sporadic and intermittent. The sediments grade up from clean limestone through carbonaceous limestone, calcareous argillite, and tuffaceous argillite to tuff. Ejection of piles of coarser pyroclastics and extrusion of lava was evidently localized and of short duration at first, but grew more general and continuous later. Some masses of volcanic material accumulated on top of limestone while deposition of limestone and argillite continued nearby.

Clearly, a single formational boundary cannot be defined by two criteria that rarely coincide. One boundary is defined by some change in the sedimentation, and another by the onset of massive vulcanism. A decision has to be made as to what to do with the volcanics. In the Alice Lake-Benson Lake area Jeffery largely was able to avoid the problem by taking the top of the clean limestone as the top of the Quatsino Formation. Correspondence with Muller and Carlisle indicates that the problem is under review.

In the Kennedy Lake area the question does not arise as to where in the sedimentary succession to place the Quatsino-Bonanza boundary because the argillite member has been arbitrarily included in the Quatsino Formation, and no sediments have been found above the upper limestone. The volcanic rocks overlying the upper limestone, however, present a problem. They can be disposed of in one of three almost equally unsatisfactory ways:—

(1) They can be designated as a new unit. However, the restricted occurrence and poor exposure on Salmonberry Mountain hardly qualify this locality for the type area of a formation.

(2) They can be assigned in their entirety to the Quatsino Formation. Bands and lenses of volcanics enclosed in limestone would have to be included in the Quatsino Formation, but there is no evidence that the volcanics on Salmonberry Mountain are so enclosed. Assuming, as is likely, that the upper contact of the upper limestone does not represent an appreciable time interval, it is deduced that vulcanism interrupted lime sedimentation. It is perhaps not unreasonable to assume that lime sedimentation persisted locally in nearby areas for a short time after vulcanism began on what is now Salmonberry Mountain, but there is no warrant for assuming that it persisted throughout the span of vulcanism represented. There is very little justification for assigning the volcanics to the Quatsino Formation.

(3) The alternative adopted follows the practice of the past 35 years of assigning all post-Quatsino, pre-batholithic volcanics to the Bonanza Group. If the name Bonanza should be restricted to post-Quatsino sediments, as Gunning recommended, the Salmonberry Mountain volcanics will be linked by name to strata with which they are not known to have any relation.

## BONANZA GROUP(?) (5)

Rocks tentatively assigned to the Bonanza Group outcrop sporadically in a broad south-trending band on Salmonberry Mountain and at one place on the extreme northwest corner of Mount Frederick. They are extensively intruded by the Older Porphyry, and the total amount of exposure within the area designated as Bonanza on Figure 2 is small. The best exposures are on the west and part of the north face of Salmonberry Mountain. The rocks there appear to be largely tuffs of varied aspect, within which there are one or two thin layers of massive green rock containing amygdule-like nodules of epidote.

Contacts between the different rock types, and banding in some of the tuffs, dip into the mountain and away from the contact with the upper Quatsino limestone, and it is clear that these rocks overlie the Quatsino. The actual contact is covered in most places, and is occupied by sills of Older Porphyry in others. At one place, tuffs appear to rest directly and abruptly on the limestone, but there is no indication of disconformity.

## ANDESITE INTRUSIONS (6)

Innumerable dykes, sills, and stockworks of dense to fine-grained dark-green to greenish-black rock intrude both limestones and argillite of the Quatsino Formation. They probably occur also in the Karmutsen Group, but none has been identified, as this rock is identical in appearance to the massive Karmutsen and the matrix of the amygdaloidal Karmutsen andesite. Four small stocks of similar rock were also observed, and are shown on Figure 2. This type of intrusive is common through the Quatsino Formation on the northern part of Vancouver Island, and has been called either intrusive greenstone or trap. Thin-sections taken from several bodies have been identified as andesite, and this term is used to describe all such bodies.

One stock intricately intrudes the lower limestone on the north face of Mount Dawley. It is about 4,000 feet long with a minimum width of 1,300 feet. It is an over-developed stockwork in which interconnected dykes and sheets have thickened to the extent that they constitute more than 50 per cent of the rock mass. The result is a stock containing large tabular inclusions of limestone. Some of the contacts are strikingly concordant, and close mapping of the moderately well-exposed rocks was necessary to verify the intrusive nature of the andesite. The limestone re-entrant in the west end of the stock forms a shallow syncline resting on andesite, the bedding in the limestone lying strictly parallel to the contact. It is not known whether andesite intrusion caused the folding or whether the andesite passively intruded beds already folded. The rock is in part medium grained, and feldspar is commonly discernible.

A second stock is shown on Figure 2 as three outcrops of diorite extending 2,000 feet west along the highway from the mouth of the creek between Mount Dawley and Salmonberry Mountain. Some parts of the exposures are definitely diorite, whereas others are clearly feldspathized andesite. The body is hybrid—as a whole it is now more nearly diorite than anything else, but genetically it appears to be a made-over andesite stock. It may at one time have been continuous with the first stock.

A third stock is exposed in the southwest wall of the Brynnor open pit and has been traced one-quarter mile southwest. It is massive dark greyish-green andesite, and has been described in some detail on page 108 in the Annual Report for 1961. At that time the body was thought to be a flow because of the following features: Some indistinct angular reddish patches, an inch or two across, along the margins suggested breccia fragments; diamond drilling showed tuffaceous argillites underlying the andesite at depth generally less than 100 feet, and indicated that the contact was nearly flat; and the uniformly fine grain seemed incompatible with an intrusion of this size. However, the contacts are not concordant with remnants of bedding in the tuffaceous argillites, deeper mining discloses that the lower contact is not flat, but rather it is in the shape of a concave wedge pointing downward, the body appears to cut across the argillite-limestone contact, and flows have not been found in the argillite member elsewhere in the area. Now it is believed that the body is almost certainly a stock. It pinches out in limestone to the northeast and is truncated by diorite on the southwest.

A fourth stock is exposed in the southeast corner of the open pit, where it is in fault contact with limestone and tuffaceous argillite. Core from diamond-drill holes to the east and southeast and a few widely scattered outcrops to the south and southwest suggest that the andesite underlies an appreciable area and forms a roughly tabular body trending northeast, and enclosed by diorite and tonalite at both ends.

Parts of some andesite bodies appear bleached. In thin-section the bleaching appears to be due not only to the alteration of amphibole to light-coloured chlorite, but also to the formation of carbonate, garnet, clinozoisite, and epidote. The fresh andesite is a felt of fine-grained feldspar and fine to very fine-grained amphibole, in which there are a few small scattered phenocrysts of feldspar.

The profusion of andesite intrusions in the Quatsino Formation wherever it has been identified has led to the belief that they are an intrusive counterpart of Bonanza vulcanism. Some would represent flow feeders, but a great many evidently have no connection with the surface.

The andesite intrusions have not been dated directly, but their age is bracketed by the Middle Jurassic age of the batholithic intrusions and the Middle Karnian to Early Norian age of the Quatsino Formation. If they are the intrusive counterparts of Bonanza vulcanism, they probably are of varying ages, within the time limits of the vulcanism. As a group they would be coeval with the Bonanza Group, and hence partly of Late Triassic but more commonly of Early Jurassic age.

## OLDER PORPHYRY (7)

The Older Porphyry occurs as dykes, sheets, and small stocks in restricted parts of the area. It consists typically of phenocrysts of white plagioclase, 1 to 5 millimetres across, in a dense dark-brown to black groundmass. Locally the groundmass is light to medium green. On Salmonberry Mountain the Bonanza volcanics are extensively intruded by small bodies of the porphyry, and at the southwest corner, porphyry exposed in the creek bed contains blocks of limestone. Abundant exposures of the porphyry astride this creek are shown as an irregular stock on Figure 2, primarily to produce an area large enough to show at the map scale. In reality the exposures appear to be of much smaller stocks, which contain abundant inclusions of the invaded rock, and of a large number of dykes and sheets. The porphyry is in turn intruded by batholithic diorite.

A larger mass of the Older Porphyry occurs on the south edge of the map-area, about a mile south of the Brynnor mine. It contains no older rocks but is extensively and intricately intruded by diorite and granodiorite.

The Older Porphyry is difficult to recognize where it is bleached and partly altered. Several small bodies have been identified by company geologists in the open pit and in some drill cores. Several patches of Older Porphyry occur in the light-green rock on the two underground levels and appear to grade into it, but in thin-section the green rock much more closely resembles andesite or fine-grained diorite. Also, one thin-section straddles a contact between the green rock and Older Porphyry and shows that it is sharp. The Older Porphyry thus forms isolated bodies in the green rock, and these bodies are probably dykes.

In thin-section the fresh Older Porphyry is seen to consist of large and small phenocrysts of plagioclase and small phenocrysts of amphibole and biotite in a foliated fine-grained groundmass of amphibole and platy plagioclase. The phenocrysts of plagioclase and biotite are subhedral, and the phenocrysts of amphibole are markedly euhedral. The amphibole is deep brown in colour and is probably the species known as lamprobolite or basaltic hornblende. The plagioclase phenocrysts show strong normal zoning, and in some thin-sections show also weak recurrent zoning. Many of the plagioclase phenocrysts have sharp angles unrelated to the crystal form, and show truncation of the crystal and of the zoning; they have evidently been broken and scattered. The composition of the plagioclase is difficult to determine due to the strong zoning of the phenocrysts and a lack of good twinning in the plates of the groundmass. The few extinction angles obtained indicate that the groundmass plagioclase is close to the andesine-labradorite line, and when the contribution of the phenocrysts and the texture are considered, it is probable that the rock is basalt rather than andesite.

The Older Porphyry intrudes andesite tuffs assigned to the lower part of the Bonanza Group, and it is intruded by batholithic diorite and granodiorite. Its relationships with the intrusive andesite are less clear. Possibly the patches of Older Porphyry in the underground workings are dykes intruding an andesite stock, but the evidence is far from conclusive. Dykes in the open pit that have been identified by company geologists as Older Porphyry appear to transect bodies of the andesite. Since the porphyry intrudes at least the basal volcanic rocks, and since the intrusive andesite may be in part coeval with the basal Bonanza, it is possible that at least part of the intrusive andesite is older than the Older Porphyry. Unless two distinct magmas coexisted in the same area, the intrusive andesite is probably entirely older or entirely younger than the Older Porphyry and is provisionally regarded as post-andesite and therefore probably of late Early Jurassic age.

## BATHOLITHIC INTRUSIONS (8, 9)

### Distribution

Medium- to coarse-grained intrusive rocks of intermediate composition underlie the southeast half of the area. Reconnaissance observations by several persons indicate that they extend to Toquart Bay and may underlie a large part of Barkley Sound. The rocks, therefore, constitute a body of batholithic size.

That part of the batholith included within the map-area is divided into east and west sections by a large re-entrant of Quatsino and Bonanza rocks on Salmonberry Mountain. The batholith may or may not be continuous around the south end of this re-entrant at surface, but it probably continues beneath the south part of it at no great depth. The west section of batholithic rocks underlies part of the coastal plain. Outcrops thin out to the south and west, and the extent of the batholith in those directions is not precisely known. However, it does not extend to the Pacific shoreline, and, as indicated in the next chapter, it probably is truncated by a major fault. In the north a covered contact with Karmutsen rocks swings northwest to Kennedy Lake, then almost due west to the limit of mapping.

The east section includes all the batholithic rocks lying east of Salmonberry Mountain and southeast of the lakeshore belt of Quatsino limestone. It is partly split by the mine belt and the stock of Older Porphyry, but has clearly engulfed them. It extends north, east, and south beyond the limits of mapping. An irregular apophysis transects the lakeshore belt along the creek between Salmonberry Mountain and Mount Dawley. Another irregular apophysis almost bisects the mine belt. A dyke-like tongue extends north into Karmutsen rocks east of the long peninsula.

Many dykes of granodiorite and diorite intrude the mine and lakeshore belts and those areas of Karmutsen rocks lying closest to the batholith. They are present but less common on Laylee Island and the north peninsula.

Exposure of the batholithic rocks ranges from fairly good to poor. In the coastal plain large and small outcrop areas are isolated in unconsolidated deposits. In the valley south of Salmonberry Mountain a few small outcrops occur in a large area of drift. To the east and northeast there is in effect one general area of outcrop that is interrupted by patches of till and alluvium. Within the outcrop areas, exposure is poorer than in corresponding areas of Karmutsen rock, and consists largely of scattered small cliffs a few feet high and a few tens of feet long. Only in the upland area between Draw Valley and Draw Lake are naturally exposed horizontal rock surfaces at all common.

## LITHOLOGY

The batholithic rocks are uniformly massive in the sense of lacking any foliation or lineation. They range from medium to coarse grained and from light to dark in colour. Most of them contain visible quartz, but in some no quartz is apparent macroscopically. These quartz-poor rocks are generally medium grained and dark coloured, and are designated diorite. In many places they are in sharp contact with the quartz-rich rocks, and immediately west of the mine belt are clearly intruded by them. Diorite has therefore been designated as a separate unit (No. 8) in the Table of Formations and on Figure 2. The batholithic rocks containing macroscopically visible quartz vary from place to place in grain size and in colour, due to varying content of the several minerals, but it was not feasible to map contacts. These rocks have therefore been given the same map symbol and unit number, with lower-case letters indicating areas in which certain characteristics are emphasized.

The most abundant type is coarse-grained granodiorite and quartz monzonite, designated 9b. It is generally light coloured on the fresh surface, due to a low content of ferromagnesian minerals such as biotite, hornblende, and chlorite. It commonly has a pinkish cast, due to the presence of orthoclase. Locally it is markedly greenish, due to alteration of the plagioclase to clinozoisite and epidote. It has not been found east of the mine belt. Type 9a, fine- to medium-grained granodiorite and quartz monzonite, differs from 9b essentially only in grain size. The quartz and orthoclase crystals are about the same size as the plagioclase, and exposures appear strikingly uniform. This type is restricted to a zone in the southwest part of the area and to three small exposures south of Salmonberry Mountain. Type 9c, coarse-grained tonalite and quartz gabbro, appears to be restricted to the part of the area south and southeast of the mine belt. It is generally coarse grained and light coloured like 9b, but lacks the pinkish cast, appearing white or light grey. Thin-sections confirm that it contains no orthoclase and disclose that the plagioclase is much more basic than in 9b. It is therefore a distinct rock type, but might be difficult to separate in the field were it not for the intervention of the mine belt. Under the designation 9d are included tonalite that is generally medium grained and relatively mafic and some small contained patches of apparent diorite. The tonalite resembles the diorite except for possessing macroscopically visible quartz, and where clean weathered surfaces are lacking, it is difficult to distinguish from it. Most of these relatively dark quartz-bearing rocks lie to the northeast and east of the mine belt, but some are isolated in the southwest part of the area. North and northeast of the mine belt they intergrade with the diorite. The tongue that passes under the south end of Draw Lake is clearly not intrusive into the diorite, for it differs from it only in containing sparse visible quartz, and its contacts are rather arbitrary lines toward which the sparse quartz thins out and disappears.

The principal minerals of the batholithic rocks are plagioclase, quartz, orthoclase, biotite, hornblende, and chlorite. Plagioclase is an essential and even dominant mineral. In some thin-sections of diorite and 9c type it attains an estimated 75 per cent of the rock. In most it shows strong normal zoning, but rarely recurrent zoning. In large crystals the difference in composition between the centre and rim generally appears to be about 20 anorthite units; that is, if the plagioclase in the centre of the crystal happens to have a composition of 45 per cent anorthite (and 55 per cent alkali feldspar), the rim will have a composition of about 25 per cent anorthite. Less-coarse crystals show a smaller range, but in the diorite and mafic quartz-bearing rocks (9d) the composition gradient tends to be steeper. In thin-sections containing appreciable orthoclase the plagioclase crystals generally show a smaller range of composition. In a few thin-sections some of the plagioclase crystals show very narrow rims extinguishing at an angle appreciably different from that of the adjacent body of the crystal; that is, there is a break in composition indicating a thin overgrowth of more alkalic plagioclase. The occurrence of these overgrowths is sporadic and haphazard, and they are not characteristic of the rocks. The strong zoning renders accurate determination of plagioclase composition by optical methods very time consuming, and the work was not undertaken. The rough estimates that were made indicate that most of the plagioclase is andesine or basic oligoclase, and that the more alkalic plagioclase is associated with orthoclase. In the coarse-grained grey rock, unit 9c, the plagioclase is apparently basic andesine and possibly in places labradorite.

Quartz occurs in most of the thin-sections studied. It is lacking only in a third of the diorite specimens. In most of the other diorite specimens, however, it is estimated at from 3 to 8 per cent, attaining 10 per cent in only one specimen. In the macroscopically quartz-bearing rocks it ranges from 15 to 30 or 35 per cent, and shows no consistent variation between rock types.

Orthoclase is common in the felsic medium-grained (9a) and coarse-grained (9b) rocks, sparse or lacking in the mafic quartz-bearing rocks (9d), and lacking in the grey quartz-bearing rock (9c) and the diorite (8). In the southwest part of the area the quartz-bearing batholithic rocks contain from 15 to 30 per cent orthoclase and are mostly quartz monzonite. Through Mount Dawley and northwest of the mine belt they contain rather less orthoclase and rather more plagioclase and are mostly granodiorite. The mafic quartz-bearing rocks, 9d, are in minor part granodiorite, but most of them contain little or no orthoclase. The term tonalite is here used for the orthoclase-free rocks, instead of the more common term quartz diorite, in order to distinguish them from the quartz-bearing varieties of the rock that was mapped as diorite. In those rocks where it is common, orthoclase forms comparatively large crystals, as large as the quartz, which are commonly perthitic. Where it is sparse it occurs mostly as small ragged grains along the boundaries between quartz and plagioclase crystals. Microcline was not identified.

The ferromagnesian minerals, biotite, hornblende, and chlorite, vary widely in amount from one thin-section to another, even in the aggregate and when some allowance is made for alteration to epidote. Types 9a, 9b, and 9c commonly contain an aggregate 5 to 15 per cent, whereas type 9d and the diorite commonly contain 20 to 40 per cent of the three minerals, and one specimen of diorite from the southwest part of the area contains an estimated 60 per cent hornblende. The biotite-hornblende ratio varies widely and erratically, and cannot be related to other features of the rock. Hornblende predominates in some of the diorite specimens, but in many of the others the biotite, hornblende, and chlorite are more or less equally abundant. Some of the chlorite has clearly altered from biotite, but the larger part of it shows no evidence of having altered from some other mineral. In the coarse-grained rocks the ferromagnesian minerals tend to occur as ragged pockets about a millimetre across, and in the medium-grained rocks they are more uniformly distributed.

Primary accessory minerals include magnetite, sphene, and apatite. They rarely amount to more than 2 or 3 per cent of the rock.

The principal alteration minerals, in addition to some of the chlorite, are sericite, allophane, clinozoisite, and epidote. Most of the plagioclase is slightly altered to sericite, but none of it is completely altered. The orthoclase is generally considerably altered to allophane. Clinozoisite and epidote have formed by alteration of both the plagioclase and the ferromagnesian minerals and also by introduction as veinlets. In contrast to the widespread and relatively uniform occurrence of sericite and allophane, the occurrence of clinozoisite and epidote is very patchy and variable. The smaller patches appear to be related to narrow crush zones and the larger to contacts. In a few places the rock is replaced also by pyroxene and magnetite; these are described further under " Mineral Deposits."

For the most part the rock fabric is normal for granodiorite and diorite. Some thin-sections of the diorite and mafic tonalite, however, show a tendency to interpenetrating grains and a generally confused fabric similar to that of the Karmutsen andesite; the grains are much coarser than in the andesite.

The batholithic rocks, and especially the granodiorite and quartz monzonite south and southeast of the lakeshore belt, contain numerous blocks of dark greyish-green andesite, commonly 3 to 8 feet across. Some show recrystallization around their margins. A few small blocks that are technically fine-grained diorite are probably andesite blocks that have been recrystallized throughout. Most of the blocks lack distinctive primary features, and could have come from either the massive Karmutsen volcanics or the andesite intrusions. One or two blocks, however, contain amygdules and closely resemble the amygdaloidal Karmutsen. Three andesite inclusions are large enough to show on Figure 2. One is a quarter-mile north of the open pit, in the gully of a small creek. It is difficult to account for a large block of Karmutsen in this position, close to the tuffaceous argillite, and the inclusion is tentatively regarded as a small andesite stock, or remnant of a stock, that has been incorporated in the batholith. A second inclusion shown on Figure 2 is on the south slope of Draw Mountain, at the north end of the mine belt. It ranges from intrusive breccia in the west to nearly massive andesite in the east. There is a complete gradation from rock consisting of scattered inclusions of andesite in the granodiorite through intrusive breccia, in which predominant andesite is laced with granodiorite dykelets, to andesite cut by a few granodiorite dykes. The contact shown is arbitrary. To a lesser extent the granodiorite forms an intrusive breccia with the nearby diorite also. The contact between andesite and diorite is not well exposed and is partly obscured by the granodiorite intrusion, but it appears to be gradational. The third andesite inclusion lies to the northwest, on a tributary of Draw Creek. It is largely enclosed in diorite, with which it appears to be gradational, and is overlain by a patch of gently dipping limestone. The contact with granodiorite is covered, and intrusive breccia was not found. The gradational contacts with diorite suggest that a considerable volume of it may have formed by recrystallization and *in situ* assimilation of andesite. The total volume of andesite that probably was present on the southwest slope of Draw Mountain appears overlarge for an andesite stock, and these two andesite inclusions are tentatively regarded as Karmutsen remnants.

Eight limestone inclusions are shown on Figure 2. One is in the southwest part of the area, the others across the southwest slope of Draw Mountain and northwest of Draw Lake. Only one is enclosed in granodiorite. The others are either in diorite or are strung along the contact between diorite and granodiorite. They appear to be discrete blocks, with sharp contacts, and lack apophyses of diorite.

### RELATIONSHIPS

The batholithic rocks, for the most part, intrude Karmutsen and Quatsino rocks, Intrusive Andesite, and Older Porphyry, and are intruded by the Younger Porphyry and the Kennedy Intrusions. Contacts between diorite and andesite, both Karmutsen and intrusive, appear to be gradational in several places, but this feature is no indication of the age of the diorite because it clearly intrudes Quatsino argillite and Older Porphyry.

Internally, the relationships are partly gradational and partly intrusive. East of the mine belt the coarse-grained tonalite grades to mafic tonalite by decrease in grain size and increase in content of ferromagnesian minerals, and the mafic tonalite grades to diorite by fading out of the visible quartz. This latter gradation is well demonstrated by the " tongue " of mafic tonalite that crosses the south end of Draw Lake. Quartz is sparse throughout, and the rock could as readily be regarded as diorite that has locally developed a little quartz. These rocks along the east and northeast edges of the area thus appear to be contemporaneous.

The wedge of coarse-grained granodiorite and quartz monzonite extending northwest from the mine belt is, on the other hand, demonstrably intrusive into the diorite. It transects diorite-limestone and diorite-andesite contacts, it presents a sharp contact with the diorite, lacking any gradation in texture or mineralogy, and locally, as near the andesite inclusion at the northwest corner of the mine belt, it forms an intrusive breccia with the diorite. Granodiorite dykes are common in the diorite. Granodiorite has not been found in contact with the tonalites, but in view of their apparent contemporaneity with the diorite, it presumably is somewhat younger than them also.

The diorite to the west and south of the mine belt has not been found in contact with the tonalites, but it has been intruded, in places rather intricately, by the coarse-grained granodiorite. Since it does not differ in character from the diorite on Draw Mountain, it probably is of the same age, and may have been continuous with it prior to intrusion of the barb of the granodiorite wedge.

Between the northeast angle of Mount Dawley and the creek just north of the delta, the granodiorite is separated from the limestone by some 50 to 200 feet of diorite (not shown on Fig. 2). The contact between granodiorite and diorite is gradational, and the diorite is probably a marginal facies of the granodiorite.

In the southwest part of the area the coarse-grained granodiorite and quartz monzonite grade into and form an incomplete shell around the medium-grained facies. The contacts between coarse-grained granodiorite and diorite are not well exposed, and it is not apparent whether they are intrusive or gradational. The mafic granodiorite at the south edge of the area, however, contains blocks of diorite, and on the east side of the logging-road it forms an intrusive breccia with the diorite. It may be contemporaneous with the felsic granodiorites and quartz monzonites.

In both the eastern and southwestern parts of the area, therefore, the batholithic rocks appear to fall into older and younger divisions. The diorites and granodiorites-quartz monzonites are assumed to be respectively correlative between the two parts of the area on the basis of similar lithology. If they are not actually correlative, the intrusive history is rather complex.

### Formation of the Batholithic Rocks

Most of the batholithic rocks would appear to have been intruded as magma. The evidence for intrusion includes truncated beds, beds pried apart by offshoots of the intrusion, dykes, intrusive breccia, rafted blocks, and secondary deformation of beds and folds. A small part of the diorite probably has been, and part of the mafic tonalite along the east edge of the area may have been, produced by recrystallization and metasomatism. The other batholithic rocks exhibit only features indicative of intrusion. Finally, the prevalent strong normal zoning in the plagioclase crystals is more likely to have been produced by crystallization from a fluid than by recrystallization under metamorphic or metasomatic conditions.

There are five places in the area where the diorite grades into older rocks. One is at the contact with the main mass of Karmutsen volcanics at the north edge of the area, and another is southwest of Draw Mountain, where two patches of andesite are interpreted as Karmutsen remnants. In both places the grain size increases over about 100 feet from that typical of the andesite to that typical of the diorite. The transition zone might be interpreted as a chilled border facies of the diorite, but it is more likely recrystallized andesite. The hybrid diorite north of Salmonberry Mountain is inferred above to be feldspathized andesite. On the southeast side of the mine belt the narrow remnants of argillite show a transition across strike from normal argillite against the limestone through migmatite and gneissoid diorite to massive diorite. It is not clear whether the diorite here has resulted from digestion of the argillite by magma or from high-temperature metasomatism that was preceded by localized intense stresses. At the north end of the open pit and in the scattered exposures to the west of it, the argillite is strongly metamorphosed. Banding has been completely obliterated, andesite dykes have become poorly defined greenish patches, and the over-all grain size approaches that of diorite. In a drainage ditch just above the pit rim, the contact with the diorite appears to be gradational. However, the pit wall discloses several patches of ramifying dykelets of light-coloured diorite that appear to be incipient intrusive breccia. The amount of diorite produced here by recrystallization and metasomatism is probably small.

The diorite exhibits sharp contacts with limestone, and lime silicate minerals are normally lacking. Northeast of the delta, however, the narrow diorite border zone of the granodiorite contains considerable pyroxene, and might conceivably be ascribed to replacement of limestone. On the other hand, magnetite accompanies the pyroxene and at one place forms a small massive body that clearly replaces the diorite; the pyroxene probably is also a subsequent development. Pyroxene and epidote occur in diorite adjacent to a patch of limestone west of Mount Frederick, but they clearly were not involved in its origin. Thin-sections show that the diorite has locally been intensely sheared and crushed, and that the pyroxene and epidote have been formed subsequent to the cessation of shearing. Thus diorite can nowhere be demonstrated to be the product of metasomatism of limestone.

In other places the diorite is clearly intrusive into the older rocks. Tongues of it intrude Older Porphyry at the south end of Salmonberry Mountain and west of the Draw Valley at the south edge of the area. On the west side of the mine belt north of Draw Creek, argillite beds are truncated by the main body of diorite and are pried apart by diorite apophyses. In the northeast corner of the mine belt a band of diorite slices across argillite beds. West of the mine belt and north of Draw Creek, also, the fine- to medium-grained diorite contains angular blocks of coarse-grained diorite. Apparently some body of coarse-grained diorite has been broken by intrusion of the normal type. On the northwest corner of Mount Redford, across from the open pit, the diorite underlying the argillite contains blocks of andesite, which are locally abundant enough to constitute the rock an intrusive breccia. This andesite presumably was intrusive into limestone that underlay the argillite. The normal pattern of ramifying andesite dykes is not recognizable, and, therefore, it would appear that the dykes have been broken up and the fragments moved around. This is ascribed to intrusion of diorite magma.

The mafic tonalite has a rather high content of ferromagnesian minerals for a tonalite, contrasting with the coarse-grained tonalite in this respect, and several thin-sections disclose a fabric similar to that of the andesite. Since most of it is found in a position that should once have been occupied by Bonanza volcanics, it may have been produced from them by recrystallization and the introduction of silica and a little potash. On the other hand, it has obliterated most of the upper limestone, and it does not appear to have done so by metasomatism. Lime silicate minerals were not found in and around the two remnants of the limestone on upper Redford Creek, and where the contact with limestone is actually exposed, it is marked by a narrow breccia zone consisting of blocks of both limestone and argillite in the tonalite. If this zone were a metasomatic pseudobreccia, it should contain only limestone blocks where it is adjacent to limestone. It is therefore probably an intrusive breccia, and the immediately adjacent tonalite is intrusive. Adjacent to the argillite, vaguely defined patches of argillite are present in the tonalite, and could be interpreted as remnants of either metasomatism or assimilation. Elsewhere the mafic tonalite is in contact only with diorite and coarse-grained tonalite, with which it intergrades. It is therefore impossible to estimate how much of the mafic tonalite may be intrusive and how much metasomatic.

The coarse-grained granodiorite and quartz monzonite east of Salmonberry Mountain and northwest of the mine belt exhibit most of the characteristics of active, forceful intrusion of magma. On the northwest slope of Mount Dawley, limestone beds are both transected and wedged up by an offshoot of the intrusion. In the creek bed nearby, bedding in the limestone is highly contorted. Dykes of granodiorite occur in the limestone, and are fairly common in the Karmutsen volcanics northward along the highway. Dykes and small stocks of granodiorite intrude the diorite, and some contacts are marked by intrusive breccia consisting of blocks of diorite in a granodiorite matrix. And the main mass of coarse-grained granodiorite and quartz monzonite west and northwest of the mine belt has the form of an intrusive wedge transecting all the older rocks. A spur of this wedge nearly bisects the mine belt.

It is significant that the large wedge is rather thickly strewn with blocks of andesite. Structural considerations indicate that, prior to intrusion, much of the rock in this area should have been limestone. Possibly the limestone was completely digested, leaving only disrupted blocks of the ubiquitous andesite dykes as inclusions in the granodiorite. It is surprising, however, that some limestone inclusions did not survive near the limestone contact. Also, the abundance of the blocks would imply an unusually high concentration of dykes, whereas the density in the adjacent limestone of the lakeshore belt is about average. Finally, a few of the blocks contain amygdules similar to those in the Karmutsen volcanics. Most of the andesite inclusions probably are uprafted blocks of the Karmutsen volcanics. The total absence of limestone inclusions would be explained if they were uprafted to levels above the present erosion surface, and thus have been eroded away. Uprafting of blocks of andesite would in turn imply a rather strong upward current in the lighter magma.

Evidence as to the mode of origin of the batholithic rocks in the southwest part of the area is meagre. The relatively acidic composition of most of the rocks would tend to indicate that there was little assimilation of andesite or limestone. There are few inclusions of andesite, and the only limestone inclusion is in diorite. The pattern of an elongate medium-grained core and a partial coarse-grained shell may represent intrusion along a fault or other line of weakness.

### Age

A sample of coarse-grained granodiorite was collected from a rock cut on the Redford Creek logging-road, at the bend about a quarter-mile southwest of the bridge across Redford Creek. A potassium-argon determination by the Geological Survey of Canada on a biotite concentrate from the sample yielded an age of 167 million years. The biotite was estimated to be about half altered to chlorite.

This sample is from a tongue which clearly intrudes diorite and evidently represents part of the last major intrusive activity in the area. There is thus no indication that the rock might have been reheated after consolidation. The alteration of biotite to chlorite was probably deuteric and consequently should have had no effect on the potassium-argon ratio. The age determined is therefore the age of consolidation of the granodiorite.

The diorite, and probably also the tonalites, are older by an unknown amount. The relations described above would indicate that the diorite was solid when the granodiorite and quartz monzonite were intruded. Calculations made elsewhere (Larsen, 1945) indicate that the interval required for the solidification of the diorite was at least of the order of several thousand years. A maximum age difference of a few million years is indicated by the number of events that must be crowded into Early and Middle Jurassic time. If the diorite-tonalites and granodiorite-quartz monzonite are regarded as two waves of intrusion from the same magma, the age difference is probably not more than one or two million years. The batholithic rocks are probably all of Middle Jurassic age.

## FELSITIC INTRUSIONS (10)

There are a number of small white to pale buff, aphanitic to aplitic bodies within the coarse-grained granodiorite and quartz monzonite. Some resemble massive light-coloured tuffaceous argillite such as is found in the open pit. Three bodies on and near Mount Dawley are shown on Figure 2; their contacts are poorly exposed, and it is uncertain whether these bodies are inclusions or intrusions in the granodiorite. A few irregular dykes intrude granodiorite north of the mine road, and another body occurs in the underground workings of the mine. South of the area mapped, a reconnaissance west of the north end of Maggie Lake disclosed a small stock of fine-grained granodiorite intruding the coarse-grained tonalite. This stock may be correlative with the coarse-grained granodiorite, with the felsitic intrusions, or with neither.

In thin-section these intrusions are variable. Those on and near the summit of Mount Dawley consist almost entirely of andesine feldspar that is variably altered to epidote and minor chlorite. A dykelet north of the mine road is of quartz monzonite composition. The body in the underground workings consists of a striking graphic intergrowth of quartz and plagioclase.

These small bodies may not all be of the same age. They are grouped together here because none of them appears to belong to any other unit. The epidote alteration of the andesine rocks on Mount Dawley suggests that they cannot be much younger than the enclosing granodiorite. They may be inclusions of some older rock, but fine-grained andesine rocks are not known elsewhere in the area. The dykelets north of the mine road are reasonably interpreted as a late stage of the granodiorite intrusion, but there is no definite evidence of this. The graphic rock underground is partly replaced by magnetite; therefore, it too may be a late stage of the granodiorite intrusion.

## YOUNGER PORPHYRY (11)

A number of grey porphyry dykes intrude magnetite and skarn in the open pit and underground, and intrude various batholithic rocks on both sides of Redford Creek within a mile of the pit. Their distribution appears to be restricted. Most of the dykes are from 5 to 20 feet thick, and none is large enough to show on Figure 2.

The Younger Porphyry lacks the dark groundmass of the Older Porphyry, and where both rocks are fresh they are distinguished readily enough in exposures or hand specimen. In thin-section, however, the rocks are similar. The plagioclase phenocrysts show strong normal zoning and moderate to intense recurrent zoning. The amphibole is lamprobolite, and both it and the biotite are deeply coloured. The groundmass is a felt consisting principally of plagioclase and amphibole. The groundmass plagioclase has a composition of 50 per cent anorthite, and the rock may therefore be termed a basalt porphyry. The dykes seen underground and a dyke that transected magnetite in the open pit are fresh, but other dykes in the pit and to the northeast that also appear to be Younger Porphyries show considerable alteration to sericite and chlorite.

In order to try to bracket the age of the magnetite, a sample was taken from the above-mentioned dyke in the pit that clearly transected magnetite. The Geological Survey of Canada reported an age of 121±40 million years from a biotite concentrate from the sample. The Younger Porphyry is therefore most likely of Early Cretaceous age.

## KENNEDY INTRUSIONS (12)

Many dykes, and a few small stocks, of basalt and gabbro intrude most of the other rocks west, north, and east of Kennedy Lake, and are named therefrom. They are particularly common just north of the mine road and east of the delta, where they intrude coarse-grained granodiorite. They also occur sporadically in Karmutsen rocks northward along the east side of the lake, and on Laylee Island and the north peninsula. A stock intrudes Karmutsen and Quatsino rocks west of the lake. Two narrow dykes intrude most of the other rocks in the north end of the open pit. None has been certainly identified south of the mine or west of the delta along the south side of the lake.

The rocks are dark grey or dark green to black on fresh surfaces and weather brown. The weathered surfaces are commonly rounded and friable. Some dykes contain coarse pyrite cubes. The margins of the wider dykes are noticeably chilled. Some dykes resemble the andesitic inclusions in the granodiorite, but the brown weathering, chilled margins, tabular form, fracture pattern related to margins, and apophyses usually distinguish them.

In thin-section the Kennedy Intrusions are characterized by common pyroxene and generally by markedly calcic plagioclase, which shows strong normal and recurrent zoning. In most sections the plagioclase is fresh, but in some it is partly altered to chlorite or generally altered to allophane. Both hornblende and actinolite are commonly present, the former largely altered to serpentine, the latter penetrating the plagioclase crystals.

The Kennedy Intrusions intrude coarse-grained granodiorite, but their age relative to the felsitic intrusions and the Younger Porphyry is not altogether certain. They have not been found in contact with any of the felsitic intrusions. A dark dyke that evidently belongs to the Kennedy Intrusions transects a light-grey porphyry dyke in the north part of the open pit. The light-grey dyke is thought to be Younger Porphyry because it intrudes a complex of rocks that have been strongly recrystallized, apparently by the nearby diorite. In the pit the Kennedy dykes show grooving and polishing along some faults, but are not noticeably offset, whereas the Younger Porphyries commonly show offsets of several feet. Tentatively, the Kennedy Intrusions are regarded as younger than the Younger Porphyry.

## ROCKS ON PACIFIC SHORELINE

These rocks occur outside the map-area proper, but are indicated on Figure 3. They are exposed on isolated headlands and islands adjacent to Long Beach and Florencia Bay, and more generally on the Ucluth Peninsula to the southeast. They are separated from Karmutsen, Quatsino, and batholithic rocks to the east and northeast by a broad area of unconsolidated deposits.

The rocks appear to be moderately well bedded and sorted, but the lithology is lensy, with rather abrupt lateral changes. The principal rock types are feldspathic sandstone, arkose, and argillite, with lesser greywacke, limestone, and possibly some tuff. In some places the beds are nearly flat, undulating gently over minor swells. In other places they are almost vertical. They have been intruded by a few small felsitic dykes.

The age of these rocks is not known. The abundance of feldspar suggests that they were derived from erosion of the batholithic intrusions, and hence that they are younger than Middle Jurassic. It is inferred from their local strong deformation that they are pre-Oligocene.

## QUATERNARY DEPOSITS (13)

Unconsolidated clastic sediments cover a considerable part of the Kennedy Lake area. Deposits on the coastal plain and on the floor and lower walls of the Draw Valley are mostly gravel, sand, and silt, whereas the overburden at higher elevations appears to be largely boulder clay. However, gravel pits at the junction of the Kennedy highway with the Ucluelet–Tofino road, just south of the southwest corner of the area, show a near-surface layer about 2 feet thick that may be till. This layer underlies the soil and rests abruptly on a thick layer of sand. It consists of abundant pebbles and cobbles in a sparing matrix of light-brown clay. Stiff grey clay was seen in two places: beneath sand at the north end of the open pit in Draw Valley, and at the northwest end of Florencia (Wreck) Bay. At the latter place it contains cobbles and is overlain abruptly by brown gravel and sand. It may be marine. Dolmage (1920, p. 18) gave the name Wreck Bay Formation to the unconsolidated deposits extending inland from Florencia Bay and Long Beach.

The geologic history represented by the unconsolidated deposits probably was rather complex. For example, there are several indications that there was at one time considerable drainage from south to north in Draw Valley. These include the big delta on Kennedy Lake and gravel deposits on the valley walls at increasing elevations southward at least as far as the north end of Maggie Lake. This drainage direction cannot be explained in terms of the present physiography. Again, if the layer at the top of the gravel-pit section is till, it would indicate that there has been no alluvial deposition on that part of the coastal plain since it was last overridden by ice. A marine invasion is hinted at by the cobbly grey clay rising to some 30 feet above sea-level on Florencia Bay.

The till presumably is Pleistocene in age. Most, if not all, of the alluvial deposits are probably Pleistocene or Recent. In places they can be seen to rest on till, and conversely no alluvial deposits have been found beneath thick sections of till. It is possible that some Tertiary deposits are present, but the completely unconsolidated condition of those sediments that were seen would indicate that they are probably Quaternary.

## METAMORPHISM AND ALTERATION

Regional metamorphism is slight. Regional alteration comprises a slight alteration of feldspars to allophane and sericite and of biotite to chlorite. Local metamorphism comprises recrystallization and some metasomatism at contacts with the batholithic rocks. Skarn is the principal local alteration.

The Karmutsen Group shows very little macroscopic alteration apart from the development of epidote lenses. Slight bleaching is apparent in strongly fractured areas and adjacent to some of the larger granodiorite dykes. One thin-section from the delta shows an apparent breakdown of pyroxene to magnetite and chlorite.

The limestones are thoroughly crystallized, locally very coarse, and to a considerable extent have been bleached of their grey colour, but are not generally altered otherwise. Brucite plates have been noted in the upper limestone on Salmonberry Mountain, and diopside bands in the lower limestone on Redford Creek. A small part of the limestone in the pit has been replaced by serpentine, and a serpentine vein cuts limestone in the northwest face of Mount Dawley.

The Quatsino argillite has been converted to diorite along the east boundary of the mine belt and has been sericitized in some places. The most spectacular alteration is in the open pit, where most of the banding has been obliterated and a considerable part of the rock has been altered to garnet-epidote-pyroxene skarn. In the north wall of the pit a complex of tuffaceous argillite and intrusive andesite has been strongly recrystallized, possibly impregnated with additional material, and injected by irregular lenses and blebs of light-coloured diorite.

Some of the bodies of intrusive andesite have been irregularly bleached, and part of the resulting rock macroscopically resembles massive argillite. The bleaching appears to be essentially an alteration of the amphibole to less deeply coloured minerals, such as chlorite, serpentine, garnet, and pyroxene, or less commonly a bleaching of the amphibole itself. The partial alteration of the rock to skarn minerals is difficult to distinguish macroscopically from the partial alteration to chlorite and serpentine. In the Brynnor underground workings, rock that apparently was intrusive andesite is now a uniform apple-green colour. Thin-sections of this rock show, however, that part is fairly fresh andesite with paler-than-normal amphibole, and part consists almost entirely of pyroxene. In the open pit, epidote is usually associated with garnet and pyroxene in altered portions of the andesite intrusions.

For the most part, the batholithic rocks show only a light alteration of the feldspars to sericite and allophane and a moderate alteration of biotite to chlorite. Locally, however, they are altered to skarn. East of the delta a band about 200 feet wide adjacent to the lower limestone is variably altered to epidote and subordinate garnet and pyroxene. Another zone of skarn alteration occurs in diorite in the southwest part of the area, close to the inclusion of limestone. Smaller patches of skarn alteration are scattered through the batholithic rocks.

The porphyries show considerable alteration of feldspar phenocrysts to sericite in some thin-sections, but even the Older Porphyry shows very little alteration to skarn. The Kennedy Intrusions show some serpentine-chlorite-allophane alteration.

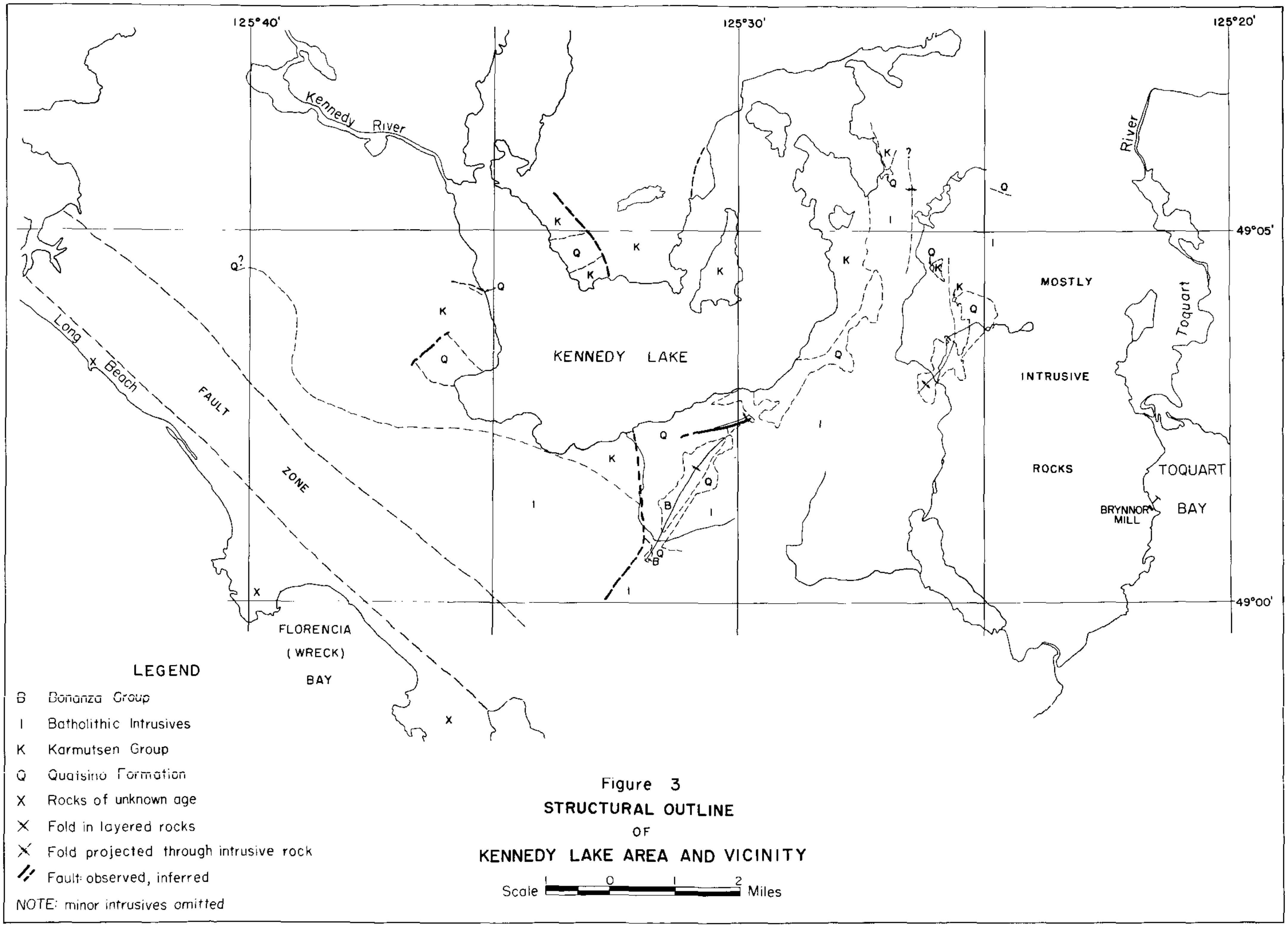


Figure 3
STRUCTURAL OUTLINE
OF
KENNEDY LAKE AREA AND VICINITY

# CHAPTER III

## Structural Geology

The principal structural features of the Kennedy Lake area and vicinity are indicated on Figure 3. These are:—

(1) An inferred major fault zone near the Pacific shore.
(2) The Blindbridge fault separating Quatsino rocks on Salmonberry Mountain from Karmutsen rocks to the west.
(3) A probable syncline through the Quatsino areas west of Kennedy Lake and on the north peninsula.
(4) A probable fold through Laylee Island.
(5) The Salmonberry Mountain syncline.
(6) The Draw Mountain anticline.

Four lesser faults are shown, on the east side of the north peninsula, west of the lake, and on Salmonberry Mountain. Small faults are very common in the open pit. The folds appear to be broad, open, and gently plunging, except where secondarily deformed. Through most of the area they trend east to northeast, but in the northeast part of the area they appear to curve to a north trend. Small warps occur on the limbs of the principal folds, and the Draw Mountain anticline has been down-buckled at the open pit.

### COASTAL FAULT ZONE (?)

Muller (1966) has projected a fault zone beneath the Quaternary deposits in the southwest corner of the Kennedy Lake area. The approximate position of this zone, as deduced from mapping in the area and from reconnaissance of rocks exposed along the Pacific shore, is shown on Figure 3. It is marked by a broad belt of continuous Quaternary cover and separates contrasting topographic forms and bedrock lithologies. To the northeast, huerfanos rise abruptly from the coastal plain and consist of bedrocks typical of the Kennedy Lake area. To the southwest, the surface is flat to gently rolling south to Florencia Bay and is hilly along the Ucluth Peninsula. These hills are subdued in comparison with the huerfanos, and every one that was seen is mantled by drift; the only bedrock exposures are along the shoreline and in road cuts. And the bedrock assemblage does not resemble any of the units to the northeast. This zone, therefore, marks a profound break in the bedrock geology and is readily interpreted as a major fault. It is inferred to be younger than, and unrelated to, virtually all the other faults described in this chapter.

### BLINDBRIDGE FAULT

The Blindbridge fault passes under or very close to a blind bridge* on the Kennedy highway northwest of Salmonberry Mountain. It extends south along the west

* This bridge has been considerably higher than the highway on either side, effectively hiding approaching traffic.

foot of this mountain, then swings abruptly southwest, along the northwest foot of Mount Frederick. Northward under Kennedy Lake it is inferred to split into three or four diverging branches.

The fault is inferred in the first place from the abrupt termination of the Quatsino Formation at the foot of Salmonberry Mountain and the juxtaposition of Kartmutsen rocks to the west. This section of the fault underlies a rather broad band of overburden, and no shear zones are apparent in the rocks on either side. It must strike approximately north. Farther south, batholithic rocks appear first on the west side, then on the east, and the band of overburden funnels into a narrow, shallow trench trending southwest. A conspicuous gash in the northwest footslope of Mount Frederick was investigated as a possible continuation of the Blindbridge Fault, but displacement on this open fracture was found to be negligible. On the other hand, there is considerable shearing of the batholithic rocks along both sides of the shallow trench, especially at its narrower points, and injection of considerable quartz. Sporadic zones of shearing and quartz injection occur in the batholithic rocks in the quarter-mile-wide strip between the trench and the logging-road. A semi-detached knob near the south border of the area would seem to suggest that a more southerly branch of the fault passes behind it, but only a minor northwesterly shear zone was found. It is evident, therefore, that the fault swings abruptly from a north to a northeast strike. At the south edge of the area the shallow trench opens out on an extensive covered area. A huerfano of granodiorite on the prolongation of the fault half a mile to the southwest is unsheared; therefore, the fault must curve to one side or the other.

The following diverging structures are inferred to be branches of the Blindbridge fault:—

(1) A well-exposed fault zone on the west shore of Kennedy Lake, northeast of the beehive-shaped hill.
(2) An inferred fault under the lake between the west shore and the north peninsula.
(3) An inferred fault through the north peninsula.
(4) A zone of shearing and relatively slight movement along the east side of the north peninsula and up the Sand River.

The fault zone northeast of the beehive-shaped hill lies within Karmutsen rocks but contains a slice of limestone. At the lakeshore the southwest contact of the limestone is marked by two open fractures, 3 feet apart, between which blocks of limestone are caught up in volcanic-appearing rock. The adjacent Karmutsen rocks are much injected by calcite veinlets. Bedding in the limestone strikes north 20 degrees west and is thrown into some steep dragfolds, which indicate that the southwest side moved southeast. To the northwest this contact is increasingly sheared. To the northeast of the limestone there is a band of sheared rusty volcanic rock as much as 40 feet wide, much injected by quartz and calcite. This rusty band is injected by two small bodies of unsheared granodiorite, the northwesterly of which also transects the limestone. To the northwest of the second granodiorite body the limestone pinches out in the shear zone, which passes under cover in a short distance.

A fault is postulated between the west shore and the north peninsula because apparently extensive limestone on the peninsula does not reappear on strike on the west shore. The fault slice of limestone just described is not a continuation because it is separated from the shore along most of its length by the shear zone and by massive Karmutsen rocks. The logical continuation is the area of limestone southwest of the beehive-shaped hill, extending inshore from the large bay. With so much of the rock covered by water, it is futile to speculate on the actual manner of dislocation. The net result, however, appears to be that the band of limestone has been displaced considerably to the left on two diverging faults, and that a slice of it has been caught up in the more westerly fault.

A fault through the north peninsula is inferred from the truncation of the band of limestone on the east and from the topography. As happens west of Salmonberry Mountain, there is an abrupt transition on the southern part of the north peninsula from a section of the coastal plain on the west to relatively rugged country on the east. A small creek flows southwest from Angora Lake to the coastal plain, where it turns abruptly south-southeast. Another small creek flows southeast off the end of the mountain ridge to the north (*see* Fig. 2), then turns abruptly west at the northeast corner of limestone exposure. The upper course of this second creek, the end of limestone exposure, and the lower course of the creek draining Angora Lake match well and are regarded as the locus of the fault which evidently must truncate the limestone on the east. This locus projects smoothly across the lake as a continuation of the Blindbridge fault.

Some relatively minor movement along the east side of the north peninsula is indicated in several places. There appears to be a small left-handed displacement of the Karmutsen breccia member between the main part of the north peninsula and the southeast cape, and between the cape and Laylee Island. Farther north a shallow linear depression accompanied by some shearing passes behind the promontory north of Laylee Island, as shown on Figure 3. W. I. Nelson, Jr., has reported (personal communication) indications of shearing along the Sand River, which is approximately on strike to the north of the map-area.

It is clearly impossible to prove that each of these structures is a branch of the Blindbridge fault, but this interpretation appears to be the simplest and most plausible. Each can be smoothly prolonged to a tangential junction under the south part of the lake on the strike of the Blindbridge fault. The Blindbridge fault shows evidence of considerable movement south of the lake and is unlikely to die out under 2½ miles of lake. None of these faults north and west of the lake can be matched with any known fault other than the Blindbridge fault.

The relative movement on the Blindbridge fault cannot be deduced uniquely from the present mapping. In the first place there is clear evidence of both pre- and post-batholithic movement, and there is no assurance that the direction of movement did not change. Movement on the branch west of the lake was entirely pre-batholithic and was evidently largely left-handed strike slip. Movement on the hypothetical branch between the west shore and the north peninsula should have been such as to have produced, in conjunction with the more westerly branch, a net left-handed strike slip of about 2 miles, with but little dip slip. The truncation on the east of the limestone on the north peninsula could be explained by an upthrow of at least 700 feet on the east side of the third branch of the fault, by a left-handed strike slip of about a mile, or a combination of less upthrow and less strike slip. Right-handed strike slip is unlikely. The branch along the east side of the north peninsula appears to have offset the Karmutsen breccia member about a quarter-mile to the left. South of the lake the Blindbridge fault has either offset the Quatsino Formation between 1 and 2 miles to the left or has thrown it down at least 3,000 feet on the east, or it has effected a combination of lesser movements. Clearly there has been post-batholithic movement south of the lake, but the batholith does not appear to be significantly offset, and it is likely that most of the displacement of the Quatsino rocks took place before intrusion.

## NORTHWEST SYNCLINE

A chopped-up syncline is inferred from the patches of limestone in the southwest corner of the north peninsula and west of the lake. As noted in the previous chapter, the limestone on the north peninsula is lithologically identical with the lower part of the Quatsino Formation and is flanked by rocks identical with the upper part of the Karmutsen Group. It would thus appear to rest synclinally on the Karmutsen. Unfortunately, most of the bedding has been obliterated by recrystallization, and what remains is difficult to distinguish from jointing. In the north belt of exposures (*see* Fig. 2) the apparent bedding is generally flat to gently south dipping, locally steepening to 45 degrees, and near the northeast corner of outcrop reversing to dip 25 degrees north over Karmutsen-like rocks. The south-dipping beds strike about north 80 degrees east, and the north-dipping ones south 70 degrees east. These north-dipping beds are thought to lie on the south limb of a small subsidiary syncline, from which most of the limestone has been eroded. Of the two southern outcrops of limestone, the easterly is almost devoid of bedding, but the westerly contains beds striking north 40 degrees west and dipping 30 degrees northeast. This attitude is inconsistent with the others and with the outline of the limestone area; it may result from drag on an offshore fault. In general, the syncline would appear to trend about north 80 degrees east, and to be generally broad and open, with some local complications. There is no evidence in the rocks for a fault along the easterly trending creek valley to the north.

The fault slice of limestone on the west shore contains no evidence of a syncline. Bedding in it strikes north 20 degrees west and dips 80 degrees west. The beds have presumably been dragged into subparallelism with the fault.

Two outcrops of limestone south of the beehive-shaped hill are thought to belong to a single block. This block is truncated by a fault on the northwest and is intruded by a gabbro stock in the northeast. Probable bedding in the shore outcrop strikes north 85 degrees west and dips 85 degrees south. Bedding is difficult to determine in the main area of exposure, and the internal structure of the limestone is not apparent. There are, however, some indications of bedding striking slightly south of east or directly into the gabbro stock. Before the stock was intruded, these beds must have abutted against Karmutsen rocks and presumably were separated from them by a fault. There is little surviving evidence of such a fault. Where the limestone is in contact with the volcanic rocks north of the stock, the relations are obliterated by granodiorite dykes. Southeast of the stock the volcanics are somewhat bleached, fractured, and veined by quartz. The other fault, which appears to truncate the limestone on the northwest, is marked by a distinct notch in a bedrock ridge, in which the surface in strewn with flakes of sheared volcanic rock. At the west edge of exposure this fault appears to branch, a small wedge of limestone occurring between the branches. It is possible that the limestone is present beneath deep cover just west of the logging-road, on the northwest side of the fault, and that the displacement on the fault is not much more than a quarter-mile. Bedrock is thickly covered for a considerable distance to the northwest of this block of limestone, but reconnaissances by the Noranda Exploration company indicate a string of small limestone outcrops 3 to 5 miles to the northwest and suggest a continuation or resumption of the band.

## LAYLEE ISLAND FOLD

Certain features of the fragmental member of the Karmutsen Group on Laylee Island and the southeast cape of the north peninsula suggest that it may lie in the core of a fold. As described under the lithology of the Karmutsen Group, there are two bands of well-defined fragments on the island, separated and flanked by rock that is vaguely fragmental. On the southeast cape well-defined fragments are present across the full width of exposure. It is unlikely that the bands of well-defined breccia would thicken so markedly and coalesce in so short a distance. The pattern can more reasonably be ascribed to a somewhat greater depth of erosion of a fold on one side of the strait.

It is uncertain whether this fold is an anticline or a syncline, because evidence bearing on the rock sequence is inconclusive. If it is an anticline, it fits readily into the fold pattern of the area. If it is a syncline, it implies the existence of flanking anticlines that are not otherwise indicated. It does not seem likely that the Laylee Island fold is a faulted continuation of the northwest syncline, for this would require movement opposite in sense to that on the Blindbridge fault; for the pattern of dislocation to be consistent, the continuation of the northwest syncline should lie north of Angora Lake. If the Laylee Island fold is a syncline, one anticline should be present between it and the continuation of the northwest syncline and another between it and the Salmonberry Mountain syncline south of the lake.

The inferred fold would trend northeast and should reappear near the tip of the long peninsula on the east side of the lake. The direction and amount of plunge cannot be deduced from the exposures mapped. The apparent plunge, as northeast for a syncline, could have been produced by upthrow on a branch of the Blindbridge fault.

To the southwest the fold is probably displaced to the left on the main branches of the Blindbridge fault, and the axis might be expected to emerge in the vicinity of the public beach. No breccia was identified in the few isolated outcrops along that part of the lakeshore.

## SALMONBERRY MOUNTAIN SYNCLINE

A broad syncline is outlined by Quatsino and Bonanza rocks on Salmonberry Mountain and the extreme northwest corner of Mount Frederick. The axis plunges gently southwest through Salmonberry Mountain, but on Mount Frederick it appears to plunge northeast. The northwest limb dips generally about 35 degrees; the southeast limb appears to be considerably steeper. The northwest limb is progressively truncated by the Blindbridge fault, southward to the point where the fault turns southwest, parallel to the fold axis. The southwest end and southeast limb of the syncline are engulfed by batholithic rocks. Some complication of the southeast limb is suggested by a broad area of outcrop of the upper limestone between 600 and 1,200 feet elevation on the northwest slope of Mount Frederick (*see* Fig. 2). It is not apparent whether this complication may have been a primary dragfold or a secondary disruption caused by intrusion of the Older Porphyry and the diorite.

On the north slope of Salmonberry Mountain the synclinal axis is displaced about a quarter of a mile to the left and upthrown perhaps 400 feet on an easterly fault. This fault is marked by a deep trench along the hillslope where the argillite member is present to the north. To the west the fault is lost in the lower limestone: any one of several chasms in the limestone could represent its continuation. To the east it is traced by exposures of gouge and breccia in a small creek and in the larger creek whose valley separates Salmonberry Mountain from Mount Dawley. The zone is 25 feet wide in the larger creek. The trace of the fault down to the creek suggests a fairly steep dip to the north, and hence that the vertical component of movement was high angle thrusting. East of the larger creek the fault passes under cover. It presumably should pass into limestone beyond the cover, but has not been identified. The gouge and breccia contain considerable ground-up granodiorite and diorite, indicating considerable post-batholithic movement. However, most of the displacement probably occurred prior to intrusion. For about a third of a mile the fault forms the general contact between intrusive rock to the south and the lower limestone to the north, suggesting that the fault zone may have acted as a barrier to farther intrusion. And part of the southeast limb of the syncline has been obliterated to the south of the fault, whereas it is essentially intact north of the fault.

North of the fault the synclinal axis trends only slightly north of east, and it presumably parallels the trace of the fault down to the creek. However, the axis could not be traced in the lower limestone, beyond the point at which the keel of the argillite member emerges from the hillside. No major syncline was identified in the limestone on the north slope of Mount Dawley or immediately northeast of the delta. Some minor inflections and rolls occur in the limestone bedding and in the contact with the Karmutsen Group, but in general the bedding dips southeast. Presumably a synclinal axis must have at one time intervened between these southeast-dipping beds and the Draw Mountain anticline.

In the northeast part of the area the distribution of bodies of limestone through diorite suggests that a synclinal axis originally lay to the west of Draw Lake, as sketched on Figure 3. If this phantom axis be continued south and southwest in a smooth curve, it would pass to the southeast of the limestone adjacent to the delta and on Mount Dawley. This would be the syncline required by the southeast dips, and it might also be the continuation of the Salmonberry Mountain syncline, necessarily faulted to the left in the valley between Mount Dawley and Salmonberry Mountain. No fault is now apparent there, but it could conceivably have been obliterated by intrusion of the complex tongue of batholithic rocks.

The inflections and rolls in limestone bedding and the Quatsino-Karmutsen contact plunge gently south and southwest, and suggest that the " phantom " syncline plunged similarly.

## DRAW MOUNTAIN ANTICLINE

This structure is outlined by Quatsino rocks in the mine belt. Its former continuation along the west slope of Draw Mountain is suggested by two patches of Karmutsen-like rocks in the diorite. It was initially thought to be a syncline, but several lines of evidence demonstrate that it is an anticline:—

(1) The limestone in the core of the fold is too thick to be the upper limestone, and must be the lower limestone. Considering that the limestone is exposed over close to 1,000 feet of topographic relief in fairly small areas and that it shows evidence of minor folding, it would be fortuitous indeed if a mere 350-foot member did not show inliers of older rocks and outliers of younger rocks.

(2) Beds of tuffaceous argillite on the northwest corner of Mount Redford are flat or dip gently toward the limestone. The contact with limestone is not actually exposed, but the argillite forms a bluff 300 feet high overlooking nearby limestone outcrops. If the argillite were to underlie the limestone in a syncline, the northwest face of the bluff would almost certainly mark a fault, but no indications of faulting were found.

(3) On the north bank of Redford Creek, east of the logging-road, limestone passes beneath a bluff of argillite. The transition from limestone to argillite is identical with that between the lower limestone and the argillite on Salmonberry Mountain. The beds curve up sharply from horizontal in the east to vertical in the west and appear to form a step on the east limb of the anticline.

(4) A little farther north, on the lower slope of Draw Mountain, the rocks appear to form a conformable sequence, from Karmutsen-like andesite in the west, through broad belts of limestone and argillite, to a little additional limestone which dips off the argillite to the east. This appears to be the east limb of an anticline.

The mine belt is enclosed by batholithic rocks and is considerably cut up by them. Bedding in most of the limestone and some of the argillite has been obliterated by general metamorphism and local alteration. The shape of the anticline has therefore to be inferred from meagre data, not all of which is conclusive. There are indications of considerable local complexity, some of which may have developed during the original folding, but possibly the greater part of which was caused by the subsequent intrusion and faulting.

The limbs of the anticline probably were stair-shaped in cross-section, consisting of alternating panels of nearly flat bedding and vertical or steeply dipping bedding. One flat panel is indicated by bedding in the patch of argillite, previously referred to, on the northwest corner of Mount Redford. Over most of the patch the beds lie flat or dip gently north, but toward the northwest they pass through a shallow syncline, and they dip 30 degrees east at the edge of exposure. On the southeast side of the patch the flattish beds are truncated by the batholith. The slivers of argillite in the next half-mile to the northeast show vague indications of steep bedding and may lie in a steep panel. The flat panel may have passed to the southeast.

The junction between a steep and a flat panel is displayed as a right-angle fold in a small bluff on the north bank of Redford Creek, mentioned above. There also the flat beds are truncated by an intrusion, the band of diorite that separates the western and eastern areas of argillite. Bedding in the northern part of the western area strikes about north 10 degrees east and generally dips 75 degrees east, indicating that the flat panel trends into the diorite. In the eastern area of argillite, exposures are small and scattered, and the attitude of relict bedding is difficult to determine. The width of the argillite area would suggest gentle dips, but a short distance north of Redford Creek bedding strikes north 70 degrees east and dips 50 degrees south. At the creek the patch of upper limestone seems to dip gently off the argillite.

The west limb of the anticline is even less known, because argillite is preserved for only a scant half-mile north from the open pit. The beds are essentially vertical. At the west foot of Draw Mountain, however, a small patch of limestone appears to dip gently west off an area of Karmutsen-like andesite. While this block may have been tilted by intrusion of the enclosing diorite, it may also represent a flattish panel on the west limb. Tentatively, it seems probable that the west limb was stepped like the southeast limb.

The anticline appears to plunge gently southwest between the southwest angle of Draw Mountain and the open pit, at an average angle of about 10 degrees. This trend stops abruptly in the open pit, and details of the structure to the southwest are unclear. The plan of the argillite-limestone contact approximates to a broad U-shaped curve through the pit, though there are minor irregularities. The pit exposures and diamond-drill cores indicate that the dip of the contact around the base of the U is generally to the northeast below about 230 feet elevation. Relict bedding in argillite to the southwest of the limestone dips northwest.

These complexities of structure in and near the open pit cannot readily be ascribed to faulting. Though there are plenty of fault zones of various sizes in the pit, none has been found in the right place and striking in the right direction to account for the complexities as well as to accord with the rock distribution. Because of the irregularities, the argillite-limestone contact does not appear to be a major fault, although there is local shearing along it. It seems more probable that the anticline is buckled downward and slightly backward, accompanied by plastic flowage of the limestone and its local injection into argillite.

The structure of the argillite southwest and southeast of the pit is not understood. In the south wall of the pit there are lenses of limestone in argillite that show local bedding dipping 30 degrees northwest. These lenses presumably are segments of beds in the transition zone at the base of the argillite. If the northwest dips truly represent the structure, massive limestone should emerge from beneath the argillite a short distance to the east, but it does not. Furthermore, the limestone-bearing bedded argillite overlies altered massive argillite lower in the pit wall. It must be emphasized that bedding is preserved only in small isolated patches, and that most of the argillite in the pit wall and in outcrops to the southwest and east appears massive. It is conceivable that the argillite was involved in minor folds superimposed on the anticline, and the northwest-dipping limbs were less subject to obliteration of bedding. Farther to the southwest the argillite passes under extensive cover, and the next outcrops encountered are of intrusive rocks.

## BROADER CONSIDERATIONS OF STRUCTURE

The folds are anomalous in that they trend northeast through most of the area or at right angles to the general trend of folds on Vancouver Island. The distribution of inclusions in diorite near Draw Lake suggests a syncline and anticline trending north, and conceivably this trend could continue to curve around to the northwest beyond the area. West of Kennedy Lake, segments of a syncline actually seem to trend slightly south of east. The over-all pattern of folding is therefore roughly arcuate. It probably is not due to secondary deformation of the folds by intrusion; rather, it is likely that the arcuate fold pattern influenced the pattern of intrusion. Certainly the batholithic intrusion appears to have caused minor deformation of the folds and probably was responsible for buckling of the Draw Mountain anticline at the open pit, but it is hardly credible that it could have rotated structures in the Karmutsen Group north of Kennedy Lake through 90 degrees. It has been suggested to the writer that the folds are arcuate wrinkles on the nose of a major anticline that plunges southeast. This would accord with Muller's postulate of a south-southeast-plunging uplift between Herbert Inlet and Kennedy Lake (1966, pp. 74–77).

The pre-batholithic rocks have been extensively faulted, with disruption of the folds. The batholithic rocks show only scattered shearing, with negligible displacement of contacts. They have, however, presumably been broken by the Coastal fault zone. It would appear at first sight that faulting was more common in the west part of the area, but this may merely reflect the higher percentage of pre-batholithic rocks preserved there. Several of the faults in the western part of the area can be regarded as northward distributaries of the Blindbridge fault, though two or three cannot. This spray of faults tends to an arcuate pattern, concave to the west. Where the relative displacement on faults in the western part of the area proper can be deduced, it is predominantly horizontal, with a relatively small vertical component, and on most it is left-handed. These faults, therefore, do not conform to the so-called " Cordilleran " movement, in which the dominant strike is northwest and the relative movement is right-handed. The inferred post-batholithic Coastal fault zone would appear to conform in strike. The non-conforming faults cannot be related to the folding by means of the strain ellipsoid, and it is concluded that the stress pattern changed after folding and prior to faulting.

A pattern emerges of tectonic and intrusive events scattered through a considerable interval of time. Not only was folding completed prior to faulting, but there would appear to have been an interval sufficient for stresses to build up in a different pattern. There are indications that the faulting may have been accomplished in several stages and that most of the faulting took place prior to intrusion of the batholithic rocks. The emplacement and consolidation of the batholithic rocks may have required a significant span of time, judging from intrusive relations observed between the coarse-grained granodiorite and the diorite. The pre-batholithic Older Porphyry appears to have intruded the Salmonberry Mountain syncline, and so to be post-folding, though possibly pre-faulting. It appears likely, therefore, that the folding was appreciably earlier than the 167 million years obtained from the granodiorite, and so is probably Early Jurassic or even latest Triassic.

An attempt is made in the following table to place the various events in their relative time relations and, for definiteness, to indicate the most probable age in which they occurred. The tie points are the potassium-argon ages of 167 and 121 million years for the final consolidation respectively of the coarse-grained granodiorite and the Younger Porphyry. The other events are interpolated as well as possible from general considerations. The shearing in batholithic rocks along the southwest extension of the Blindbridge fault and comminution of granodiorite by the fault along the north slope of Salmonberry Mountain cannot be dated. There would be no reason to think that they were not latest Bajocian or Early Bathonian, representing either a terminal stage of the pre-batholithic faulting or adjustment to the consolidation of the batholith, were it not for the presence of small faults transecting dykes of Younger Porphyry in the open pit. Movement on many of the faults in the pit was probably recurrent, for a lobe of magnetite is crumbled along a fault that it appears to have followed. The actual ages during which the movements occurred cannot be determined. Mapping by Jeletzky (1954) farther up the west coast of Vancouver Island indicates many faults cutting Oligocene sediments, but it is doubtful whether movement on any fault in the pit occurred so late.

*Table II.—Tentative Time-table of Lithologic and Tectonic Events*

| | Age | Kennedy Lake Area | | Pacific Shore | |
|---|---|---|---|---|---|
| | | Igneous, etc. | Tectonic. | Lithologic. | Tectonic. |
| Cretaceous | ? | Kennedy Intrusions. | | | |
| | ? | | Faults in open pit. | | Coastal fault zone? |
| | Aptian. | Younger Porphyry dykes. | | Felsitic dykes. | |
| | Barremian to Callovian. | | | | Folding. |
| Jurassic | | | | Deposition of sediments. | |
| | Bathonian. | Magnetite, skarn. | | | |
| | Bajocian. | Felsitic Intrusions. | | | |
| | | Batholithic Intrusions. | | | |
| | Toarcian or earlier. | | Faulting. | | |
| | | Older Porphyry. | | | |
| | Pliensbachian or earlier. | | Folding. | | |
| Triassic | Sinemurian (?) to Late Rhætian or Norian. | Andesite Intrusions; Bonanza pyroclastics. | | | |

It has been suggested in Chapter II that the sedimentary rocks of the Pacific shore may be post-batholith in age. If this is so, the folding of these rocks represents a second orogeny that is distinctly younger than the one that folded the Karmutsen and Quatsino rocks in the Kennedy Lake area. The felsitic dykes cutting these sediments may be of the same age as the Younger Porphyry, or older, for felsic intrusions younger than this have not been found in the Kennedy Lake area. The deposition and folding of the sediments would thus have taken place sometime between the Bathonian and the Aptian. The stresses that caused the Coastal fault zone may also have caused the faulting of the Younger Porphyry in the open pit. However, these suggestions are speculative in the absence of adequate dating of the sediments and felsitic dykes.

This pattern of igneous and tectonic events scattered through time is in line with some modern thinking (King, 1955; White, 1966), and it is clear that the batholithic intrusions are not syntectonic. It has frequently been assumed that major igneous intrusions in a belt of folded rocks are more or less contemporaneous with the folding, and therefore may be expected to owe their formation to the deformation. This view has been denounced by Gilluly (1966), who insists that contemporaneity must be proven by geologic and petrographic evidence. Billings (1937, p. 537; 1938, pp. 1035, 1042; 1942, pp. 296–297; 1945, pp. 61–62) and others introduced the concept of pre-tectonic, syntectonic, and post-tectonic intrusion. In each reference Billings makes it clear that syntectonic (synonyms: synchronous, synorogenic, para-tectonic) means that intrusion occurred during the folding and not during subsequent faulting. Gault (1945, pp. 214–217, 240) has syntectonic intrusion and consolidation contemporaneous with folding and metamorphism. Badgley (1965, pp. 360–372) distinguishes six stages of the tectonic cycle in which igneous activity may occur. In order of increasing age these are:—

6. Post-Tectonic.
5. Late-Tectonic to Post-Tectonic.
4. Late-Tectonic.
3. Syntectonic.
2. Early-Tectonic.
1. Eugeosynclinal.

Badgley explains that the difference between Nos. 5 and 6 is that No. 6 followed post-tectonic deep-seated faulting, tapping basaltic magma. The batholithic intrusions of the Kennedy Lake area are therefore late-tectonic to post-tectonic in this classification. The faults presumably facilitated intrusion, but it is not evident that the folding had anything to do with batholithic intrusion.

# CHAPTER IV

# Mineral Deposits

The only metalliferous mineral of consequence so far found in the area is magnetite. It forms two orebodies at the mine of Brynnor Mines Limited on Draw Creek and several minor bodies in other parts of the area. Gold and copper mineralization is known at several points within a few miles of the area, but virtually none has been found within it.

Thick deposits of sand and gravel floor the coastal plain and occur along the floor and lower walls of Draw Valley.

## BRYNNOR MAGNETITE DEPOSIT

The Brynnor magnetite mine is on Draw Creek, 2½ miles by MacMillan Bloedel Limited logging-road from the Kennedy highway. The camp is on the highway, 2 miles farther west and about 8 miles from the junction with the Ucluelet–Tofino road. The crusher is adjacent to the mine, and the mill and loading-dock are at New York Point on Toquart Bay, 8 miles by company road from the mine. The company holds three mineral leases covering and surrounding the deposit. Brynnor Mines Limited is a wholly owned subsidiary of Noranda Mines, Limited.

The history of exploration and development has been outlined in the Introduction, page 11. From the start of production in April 2, 1962, to the end of 1966 about 4,400,000 tons of ore was put through the crusher, and 3,060,000 tons of magnetite concentrate was recovered from the mill. In addition, some 13 million tons of waste was trucked to the waste dump. Most of this was produced from an open pit developed on the shallower of two orebodies. The deeper orebody lies a short distance to the southeast and had been developed partly for underground mining. Mining ceased in the spring of 1968 when the open-pit orebody was exhausted.

The geology of the mine is illustrated by Figures 4 to 7. The plan of the open pit (Fig. 4) and the two sections (Figs. 5 and 6) are schematic in the following respects:—

(1) Much lithologic and structural detail has been omitted in the interest of clarity.

(2) Alteration is not shown; skarn is represented by the rock it is inferred to have altered from.

(3) A great deal of interpolation has been necessary, between lift exposures in the open pit and between diamond-drill holes in the sections.

(4) The pit plan shows essentially the geology of the floor of the completed 270 bench (that is, *circa* 270 feet above sea-level) and of the lifts and remnant benches above, with some projection from observations directly above and below the 270 bench.

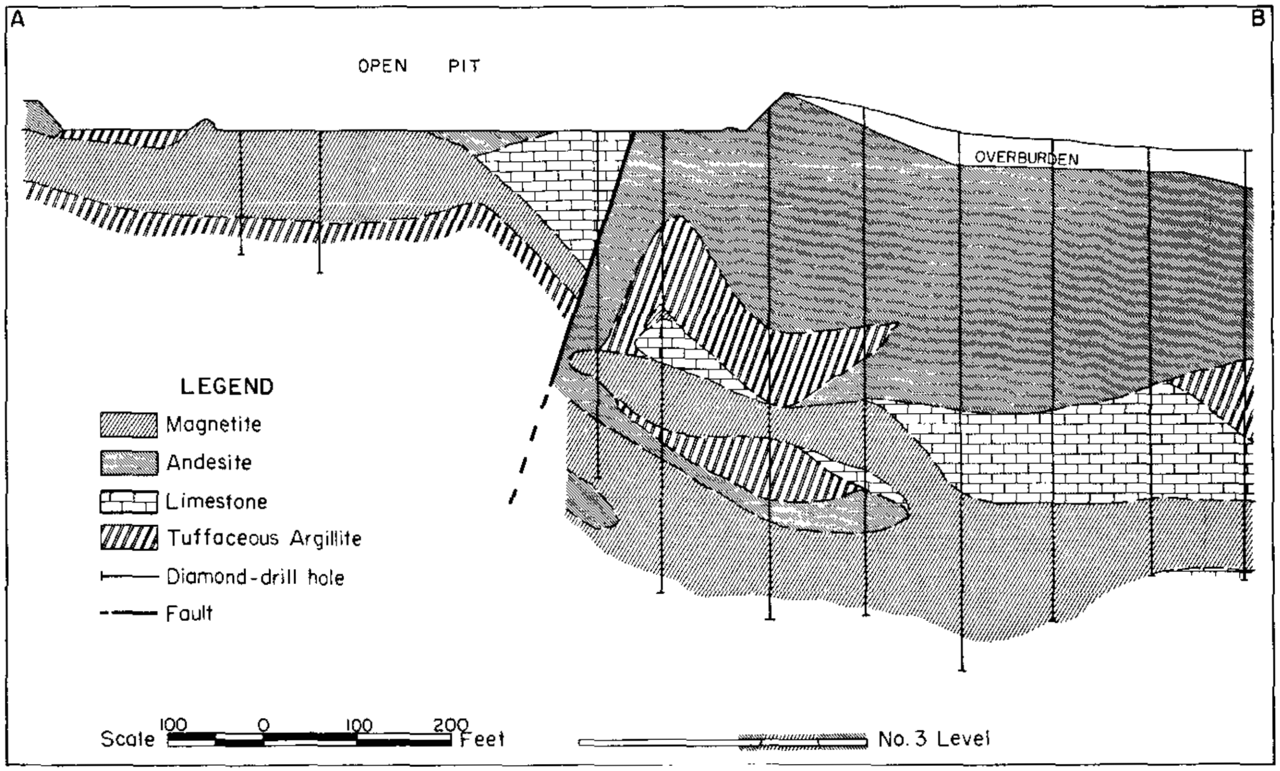


Fig. 5. Section A-B, Brynnor iron mine.

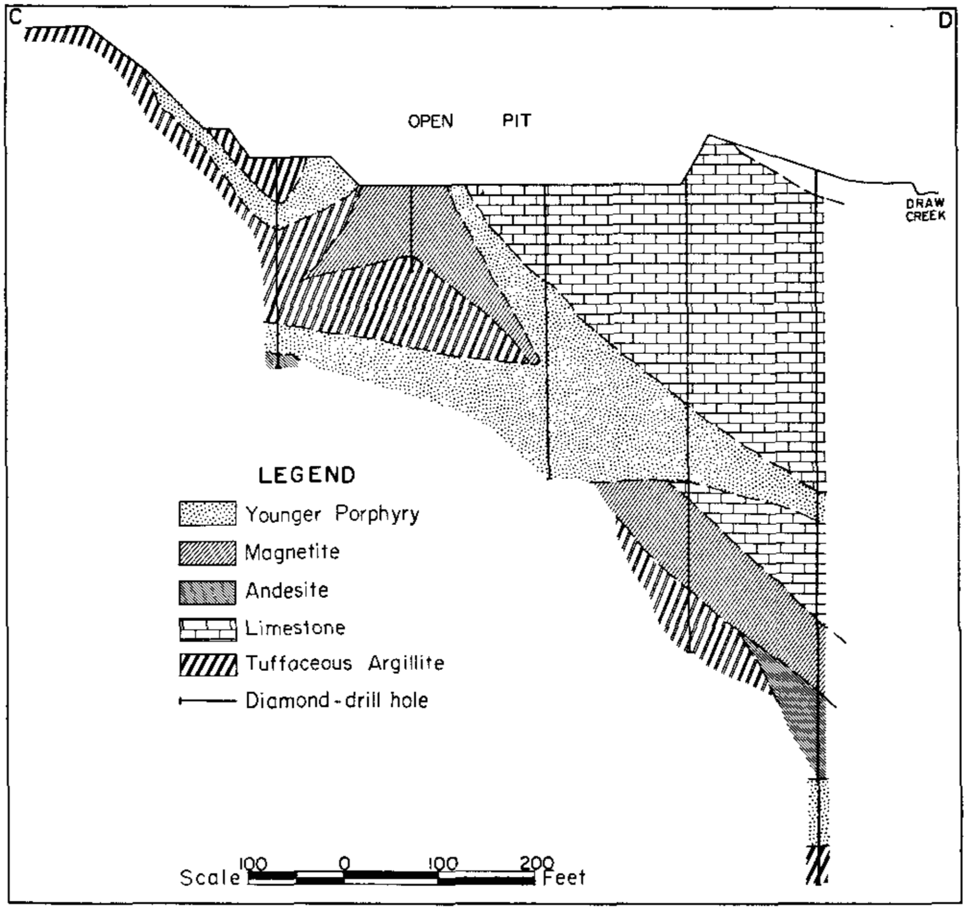


Fig. 6. Section C-D, Brynnor iron mine.

Figure 7 illustrates the complexity of detail that is present in and near the magnetite. It is not, however, representative of the associations of magnetite, in that argillite and limestone are not present there. The open-pit and underground mapping and the logging of some of the drill core are the work of the writer. In order to complete the sections, it was necessary to use company logs of a considerable footage of core, but the interpolations and interpretations have been made by the writer. Where core has been studied independently by company geologists and the writer, the logs do not differ significantly.

Most of the rock types of the Kennedy Lake area occur in the open pit, and they have been metamorphosed and altered in varying degrees. The Karmutsen Group, Quatsino upper limestone, and Bonanza Group are lacking. The coarse-grained facies of the batholithic intrusions has not been identified in the open pit, but it is intersected by underground workings near the shaft, and it is exposed on surface just southeast of Figure 4. The over-all structure is an anticline which plunges gently southwest as far as the pit. There it appears to have been buckled downward and backward. Early in the development of the pit the limestone appeared to pass beneath tuffaceous argillite to the southwest, but exposures at deeper

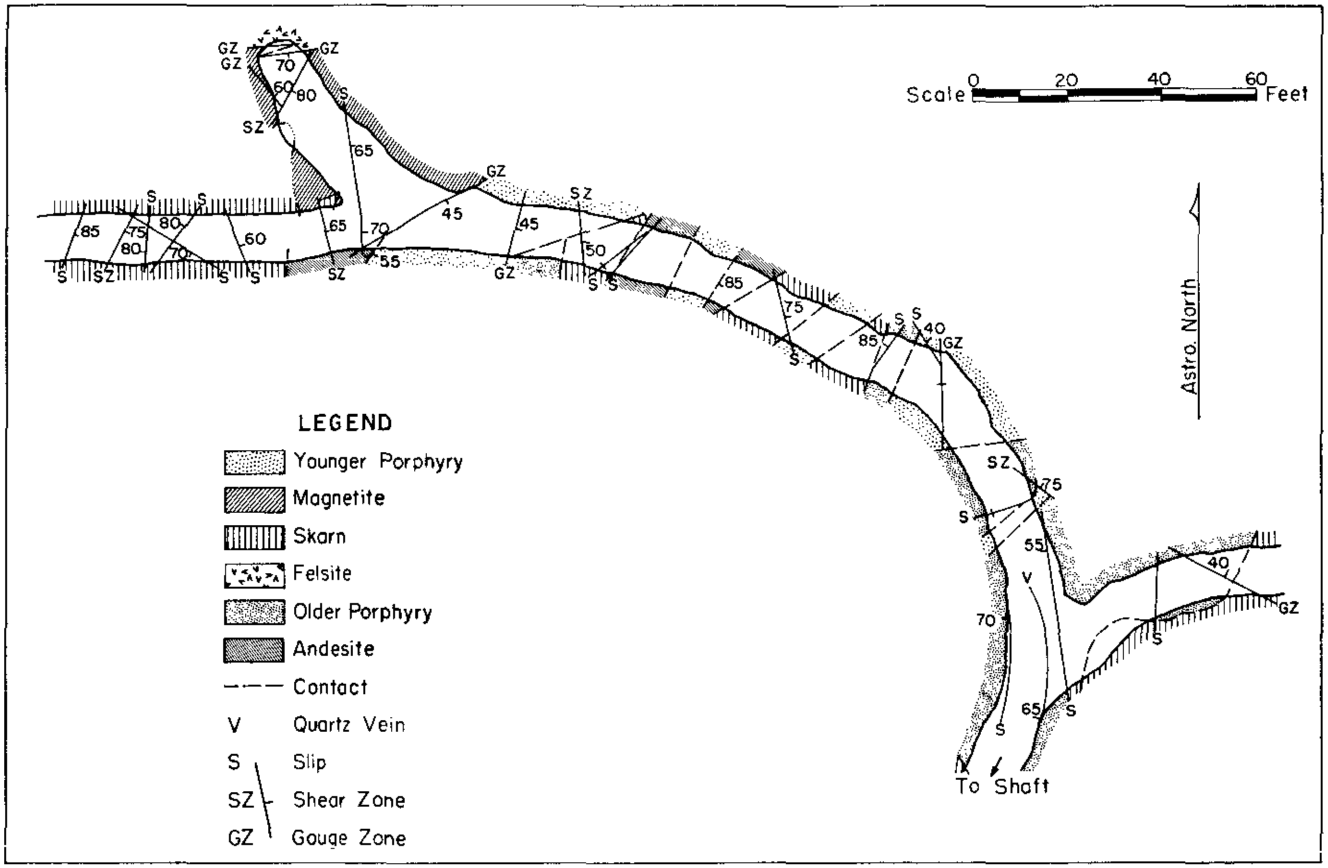


Fig. 7. Geology of part of No. 3 level, Brynnor iron mine.

levels have tended to confirm the northeast dip of the contact that is indicated by the diamond drilling (*see* Fig. 6). The rocks have been intensively broken by fractures and faults that are mostly of small displacement.

The intrusive andesite occurs as two relatively large bodies and a great many dykes and sills in the argillite and limestone. One of the larger bodies extends into the middle of the pit from the southwest. It is doubly wedge-shaped, pinching out to the northeast and narrowing downward. The other body appears to underlie a sizeable area immediately to the south and southeast of the pit. It is in fault contact with limestone and argillite in the southeast part of the pit. Much of the altered rock seen underground is likely to have been andesite. Diamond-drill cores indicate that it contains inclusions of limestone and argillite.

A host of dykes and small masses of dioritic rocks intrude the andesite and sediments. The three bodies shown on Figure 4 have been assigned respectively to the Older Porphyry, the batholithic diorite, and the Younger Porphyry. In the open pit the characteristics of these rocks are commonly obscured by bleaching and alteration, and clear contact relations between them are rare. Most of the bodies therefore cannot be certainly assigned, and the designation of two of the bodies as Older Porphyry and diorite is provisional. The dyke of Younger Porphyry, however, is relatively fresh, it contains visible biotite, and it clearly transects magnetite. It is the dyke that was sampled for age determination of the Younger Porphyry. In the underground workings the characteristics and relationships are generally clearer. The fresh Older Porphyry consists of white plagioclase phenocrysts in a dense dark-grey groundmass. It contains a host of narrow quartz veins, a half-inch or less in thickness, and mostly parallel; one such vein is shown on Figure 7. Toward the contacts both phenocrysts and groundmass grow light green, resembling partly altered andesite, but the last few inches of the Older Porphyry adjacent to the contact usually show vestiges of flow structure. No apophyses of the batholithic diorite were identified underground. The Younger Porphyry forms fresh-looking grey dykes which transect andesite, Older Porphyry, skarn, and magnetite.

The metamorphic complex in the northwest part of the open pit consists of ramifying dykelets, a fraction of an inch to 6 inches thick, of diorite in metamorphosed argillite and andesite. The metamorphism is characterized by development of medium-grained plagioclase and by convergence of the argillite and andesite toward a light-green massive rock of variable grain size.

The rocks in and near the mine have been altered in various ways and to varying degrees. The tuffaceous argillite and the intrusive andesite have been extensively altered to the skarn minerals garnet, pyroxene, and epidote. The limestone contains negligible skarn minerals itself, although some andesite dykes in it are largely altered to skarn, but it has been locally altered to serpentine, particularly along the contact with argillite. Serpentine also occurs along slips in the magnetite in the open pit, but not underground. The Older Porphyry, diorite, and metamorphic complex show only slight alteration to skarn and variable but generally minor degradation of plagioclase and amphibole to sericite and chlorite. The Younger Porphyry is not altered to skarn, but the degradation is generally more intense than in other rocks. The dyke shown on Figure 4 is a fortunate exception, as even the biotite is only half altered. These degradation effects are probably largely deuteric.

Argillite and andesite adjacent to magnetite are generally strongly altered to skarn, and bands of skarn extend into argillite to the southwest of the pit. Argillite is the more susceptible rock and is altered to greater distances from the magnetite. The gradation to skarn is well displayed in the high south wall of the pit. Near the top of the wall the argillite is mostly bleached, though showing a few small patches of dark-grey rock and some larger patches of banded rock. At about 330 feet elevation the rock is mostly white and massive and contains some fracture-veins of garnet. Below this level, garnet and subordinate pyroxene are more and more thickly dispersed through the rock, and a solid mass of skarn adjoins magnetite on the 270 bench. Through this interval the wedge of andesite is little altered, even where it is in contact with magnetite on 270 bench. Diamond-drill cores, however, show a bleaching of the andesite and then a heavy alteration to skarn as magnetite is approached. In the underground workings examined, the host rock of the magnetite appears to be andesite, and it has been very extensively altered to skarn, more so on the second level than the third. This skarn ranges from massive garnetite containing scattered small green patches with indistinct borders to a rock consisting of a garnet matrix and larger, commoner, more sharply defined green blocks. These blocks are from half an inch to 6 inches across, and commonly constitute a quarter to a third of the rock. The few thin-sections studied tend to indicate that the poorly defined patches are pyroxene and the blocks are andesite that has been extensively altered to chlorite but not to garnet and pyroxene. Possibly the alteration to skarn proceeded from a network of fractures in the andesite. Epidote is common only in altered andesite dykes in limestone.

The rocks have been broken by a great many large and small ruptures. Four of the larger ones are shown on Figure 4. Another two dozen were mapped, but are not shown because they could not be traced from lift to lift. The number of slips and fractures in the open pit probably runs into the hundreds. On Figure 7 nearly all the ruptures shown are those that persist across the crosscut. The rocks are broken by a vast number of smaller fractures. The skarn and Younger Porphyry are especially shattered, and the Younger Porphyry is most heavily water-bearing. The shear and gouge zones mapped on No. 3 level are 8 inches or less in width, but a gouge zone on No. 2 level is about 5 feet wide, and two composite zones in the open pit attain over-all widths of 30 feet and more. The slips are tight fractures with slick walls, with or without a little vein matter. They differ in character from the shear and gouge zones and appear to have formed earlier. There is no real separation between the shear and gouge zones, in character or in age. Some zones change from gouge to sheared material across a crosscut, and some of the wide zones have a core of gouge and marginal zones of schist. The structure shown on Figure 4 as truncating the Older Porphyry on the north is placed along what appears to be the principal line of shearing in an area of softening and scattered shearing that extends northwest through limestone and argillite to the andesite contact. The structure in the west part of the pit is an 8-foot-wide gouge and breccia zone through diorite which grades to a shear zone that broadens and grows diffuse through andesite. The lobe of magnetite appears to have formed in this zone, but it has in part been crumbled by later movement. The structure in the south part of the pit is mainly a gouge zone 2 to 10 feet wide, which tends to split up in the south wall of the pit. The fault contact of the andesite in the southeast part of the pit is represented in the south wall by an inconspicuous shear zone about 5 inches wide. The east wall exposes a 2-foot gouge zone and a 6-inch shear zone, separated by 8 feet of argillite which is partly altered to skarn.

Displacement on most of the ruptures is probably small. None was detected on the slips and simple fractures. Several of the shear and gouge zones offset slips and skarn-magnetite bands about a foot in crosscut walls. Only the fault along the andesite contact in the southeast part of the pit appears to have a displacement greater than about 20 feet. It has evidently dropped the limestone at least 200 feet on the east and moved it north a similar amount. The fault in the west part of the pit does not offset the andesite contact appreciably, and the apparent offset of the diorite is probably illusory, resulting from coincidence of a gouge and breccia zone with part of an irregular boundary of the diorite.

The magnetite forms two orebodies, one in the open pit and one partly explored by the underground workings. In addition, there are many veins, bands, and small lenses of magnetite in skarn near the orebodies. The orebodies lie at different levels approximately along the argillite-limestone contact, although the south end of the open-pit orebody is enclosed by altered argillite and the south end of the underground orebody is in altered andesite. The open-pit orebody appears as three separate patches of magnetite on Figure 4, because the continuous part of the orebody lay well below 270 feet elevation. Plates XI and XII are photographs of a model of the open-pit orebody that was prepared for the company by A. C. E. Mitchell, largely from diamond-drill hole information. They show the irregular shape of the orebody, including the three upward projections that appear as separate bodies on Figure 4. Each of these upward projections terminates on the north against a minor cross fault. The south cross fault appears to be the zone of shearing and softening that separates the limestone and Older Porphyry. The southerly upward projection also lies in the hangingwall of a northwest-striking fault which dips about 45 degrees southwest. This fault would coincide in strike with the fault on Figure 4 that passes through the diorite, but the dip is in the opposite direction. The model shows that at a certain depth magnetite appears below this fault, and at greater depth spreads out and merges with the main part of the orebody. There is no evidence that the magnetite has been appreciably displaced on these faults; rather, it seems that they helped to localize the upward projections. The main part of the orebody is nearly flat, but an extension continues down along the general argillite-limestone contact, as shown on Figures 5 and 6.

The underground orebody is shown only on Figure 5, where it has been sketched from diamond-drill logs and mapping of the small sections in the underground workings. It is apparently separated from the open-pit orebody by the andesite-boundary fault, and it lies at least 80 feet lower. It is unlikely, however, that the underground orebody is a down-faulted segment of the open-pit orebody, for it lies in a different geological situation. Along the section much of the enclosing rock of the underground orebody is altered andesite, whereas altered argillite encloses the south end of the open-pit orebody. Also, the narrow section of limestone enclosed by argillite just east of the fault does not match the thicker section just west of it. The discrepancy in limestone thickness can be explained by a relative northward displacement of the east block, but on reconstruction part of the underground orebody would be placed next to barren ground south of the open-pit orebody. It seems likely that most of the fault movement took place prior to formation of the magnetite. The underground orebody probably has a moderate dip to the northeast or north-northeast. It appears nearly flat on Figure 5, because the section is at least 45 degrees to the dip line. The limits of the orebody down-dip are not known. Along strike to the southeast it appears to pinch out in andesite and minor argillite.

The orebodies as outlined are more or less massive. Some interstitial calcite occurs in the north part of the open-pit orebody, and seams of serpentine occur along slips in the central part. Much of the magnetite, both in the open pit and underground, contains sparsely disseminated pyroxene. A few pockets of sulphides, generally a few inches long, are scattered through the magnetite. The sulphides include pyrite, chalcopyrite, arsenopyrite, pyrrhotite, and sphalerite. Cobaltite and skutterudite were identified by X-ray diffraction in a fragment of off-colour arsenopyrite. The dykes of porphyry also constitute an impurity in the ore as mined. The ore trucked to the crusher averaged about 42 per cent iron.

The small satellitic bodies of magnetite in the open pit differ somewhat from those in the underground workings. In the pit they are mostly bands along the contacts of Older Porphyry dykes and lenses of diverse orientations that appear to have formed along old fractures. The bands along contacts are commonly from 1 to 4 feet thick and traceable down a 30-foot lift. Some of the lenses are at least 50 feet long. In addition, there are a few pockets of magnetite, a foot or two across, at fracture intersections. The massive magnetite on No. 3 level may or may not be a downward projection of the underground orebody. If it is not, it is a relatively large satellitic body whose structural control is obscure. There are no other satellitic bodies on this level, and the skarn is almost devoid of magnetite. On No. 2 level, however, the skarn immediately adjoining massive magnetite on the south contains a considerable amount of magnetite as pockets and disseminated grains. About 100 feet southeast of the exposure of massive magnetite, massive skarn changes abruptly across a shear zone to interbanded skarn and magnetite, which continues for 100 feet east in the crosscut. The skarn bands contain very little pyroxene and consist almost entirely of garnet. The bands of both skarn and magnetite are commonly from 6 inches to a foot thick. They dip 65 degrees west at the west end of exposure and flatten to 10 degrees west near the east end. In places they show inflections suggestive of drag by an overriding block moving up to the east. Some of the magnetite bands contain sheared black material, and it is possible that most of them formed along narrow shear zones. The interbanded skarn and magnetite probably is too low in grade to make ore, and almost all the other satellitic bodies are too small to be mined.

The role of structure in localizing magnetite is evident in these satellitic bodies and in the offshoots of the open-pit orebody. The localization of the orebodies as a whole along the argillite-limestone contact may have been as much structural as lithologic. Formation of satellitic bodies along fractures and along dyke contacts that were subject to fracture would suggest that the iron was transported in a fluid. Where ore is present, the limestone structurally overlies the argillite. If most of the fractures in limestone had healed when the iron-bearing fluid was circulating, the limestone may have served as a dam. The limestone today is much less intensively fractured than the other rocks and, in view of its self-healing properties at elevated temperatures, it was probably still less fractured when the magnetite was deposited.

The physical-chemical process of formation of the magnetite is less clear. The writer has suggested elsewhere (1965) that magnetite is the end stage in a gradual replacement of the silicate minerals of the rocks by iron, the skarn minerals epidote, pyroxene, and garnet being intermediate stages. There is experimental evidence (Holser and Schneer, 1961) to indicate that transportation of the iron as ferrous chloride is feasible. The manner of oxidation and deposition of the iron is not clear, but the end result is that alkalis and aluminum, then calcium, magnesium, and silicon, are removed. In the limestone there are no intermediate stages—magnetite replaces calcite directly. It would appear that the magnetite has replaced considerably more non-calcareous rock than limestone. This may reflect both a paucity of fractures in the limestone and a greater difficulty of replacement of calcite.

## OTHER MAGNETITE OCCURRENCES

1. Half a mile north of the open pit a magnetite band a few feet wide follows the tuff-limestone contact for about 300 feet on the northwest limb of the anticline.

2. Half a mile northeast of the open pit, at the south tip of the tongue of granodiorite that nearly bisects the mine belt, about a foot of the granodiorite is more or less replaced by magnetite for about 50 feet along the limestone contact.

3. South of Redford Creek on the east contact of this tongue of granodiorite, lenses of magnetite replace granodiorite and limestone in three places. The largest lens is 4 feet wide and about 15 feet long, and appears to replace granodiorite exclusively.

4. Half a mile east of Kennedy Lake and 1¼ miles southwest of Draw Lake, adjacent to an old power-line, at the south end of a saddle between small creeks flowing south and north, a vein-like body, 8 to 10 inches thick, and some small lenses of magnetite occur in a partly altered andesite dyke in limestone about 100 feet east of the Karmutsen contact.

5. Northwest of the mine, on the east edge of the large delta, on the limestone-granodiorite contact, a diorite border facies of the granodiorite is extensively altered to pyroxene and epidote along this section of the contact. A small mass of magnetite, about 30 feet long, replaces altered diorite along the contact with a small re-entrant of limestone. A little magnetite is disseminated through altered diorite northward along the main contact.

6. In the road cut of the Kennedy highway on the northwest slope of Mount Dawley, a few square feet of massive magnetite is surrounded by overburden, but is on the line of contact between limestone and the irregular andesite stock.

## SULPHIDE OCCURRENCES

Very small amounts of sulphides occur at various places in the map-area. Those associated with magnetite in the open pit have been noted above. A little pyrrhotite and chalcopyrite are present in some of the other magnetite occurrences. Crystals of pyrite are very sparsely scattered through limestone southwest of the delta, and lenses of pyrite a few inches long were seen in limestone on Mount Dawley and in Karmutsen rocks west of Kennedy Lake.

Sulphides are also exposed in the bed of the second creek south of the Brynnor mine that is tributary to Draw Creek from the west. From about 450 feet elevation down to the next major bend, this creek follows a zone of weak shearing in a complex of Older Porphyry and diorite. Pyrite, pyrrhotite, chalcopyrite, and arsenopyrite are sparingly disseminated through the sheared and adjoining massive rock. A grab sample of some of the more sulphidic material from 325 feet elevation assayed: Gold, *nil;* silver *nil.* A spectrochemical analysis disclosed only a trace of copper.

# INDEX

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Plate I. Coastal plain from southeast, showing huerfanos. Beehive-shaped hill prominent. Mount Colnett in right distance.

Plate II. Coastal plain, looking northwest from beehive-shaped hill.

Plate III. North peninsula, Draw Mountain, and Mount Redford.

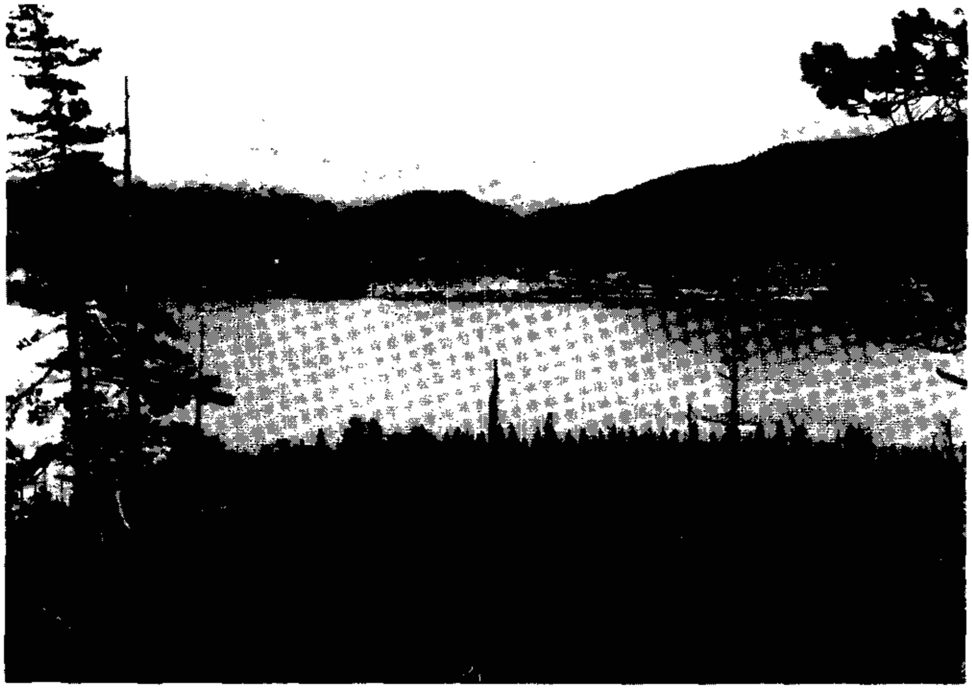

Plate IV. Delta at north end of Draw Valley. Mount Dawley to right, and Laylee Island in foreground.

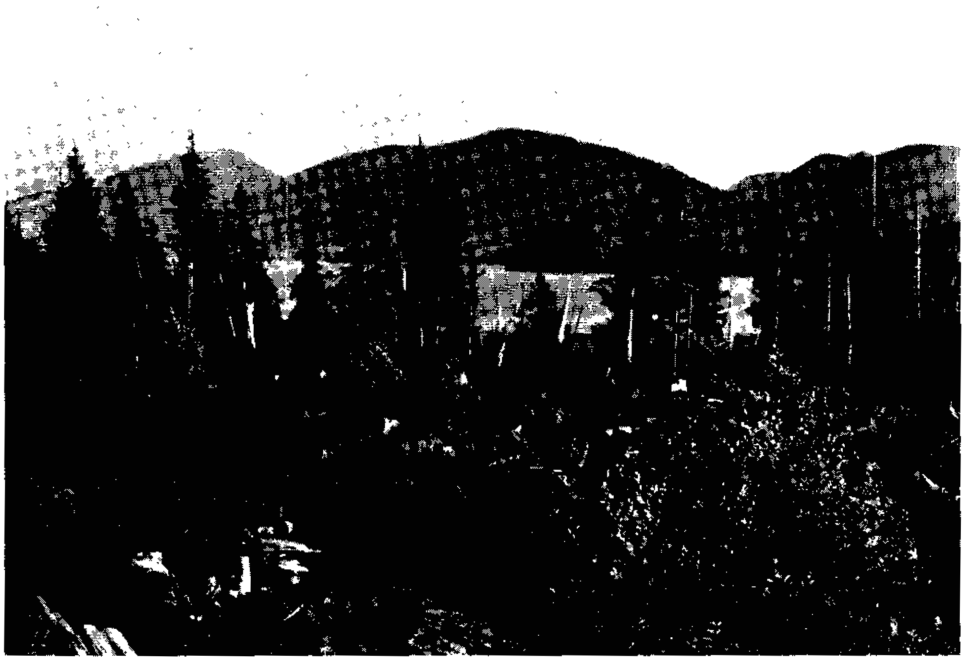

Plate V. Mount Dawley, Salmonberry Mountain, and Mount Frederick.

Plate VI. North peninsula and south end of Laylee Island.

Plate VII. Brynnor open-pit mine and vicinity in 1963. Crusher building and coarse-ore stockpile are to right of and below waste dump. High-lead spar of logging company in foreground.

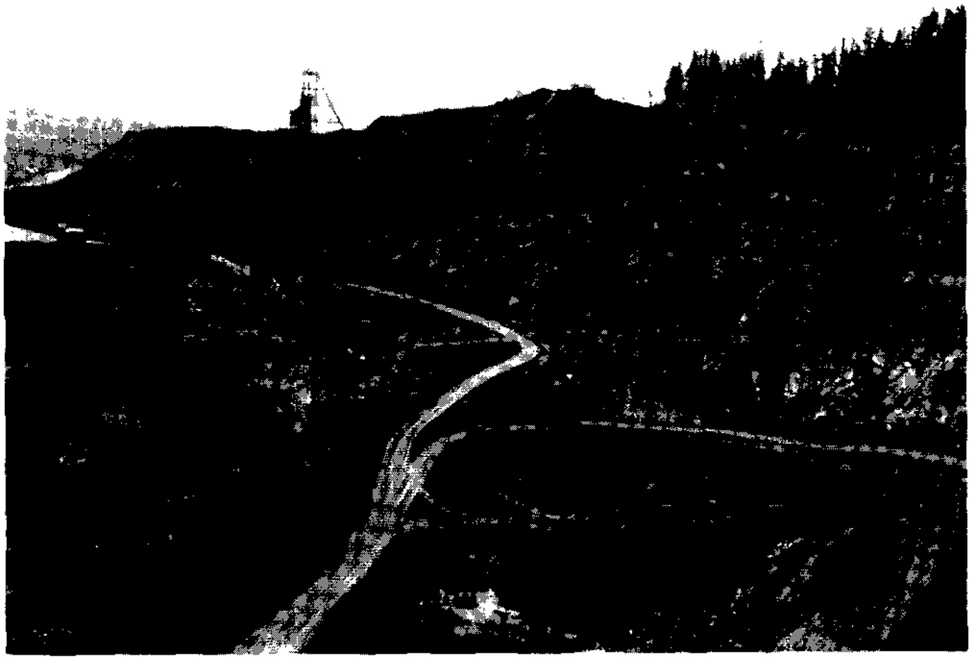

Plate VIII. Open pit and headframe in 1965. Sheeted jointing dips to left in headwall.

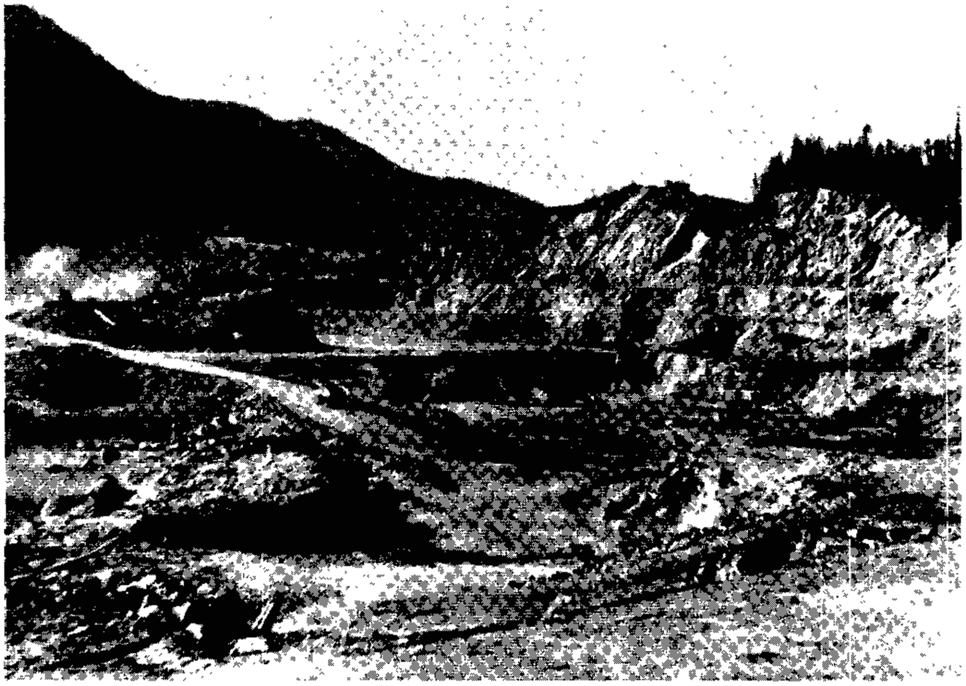

Plate IX. Open pit in 1962. Lenses and tongues of magnetite show in lifts above and below wagon drill, and in lower left.

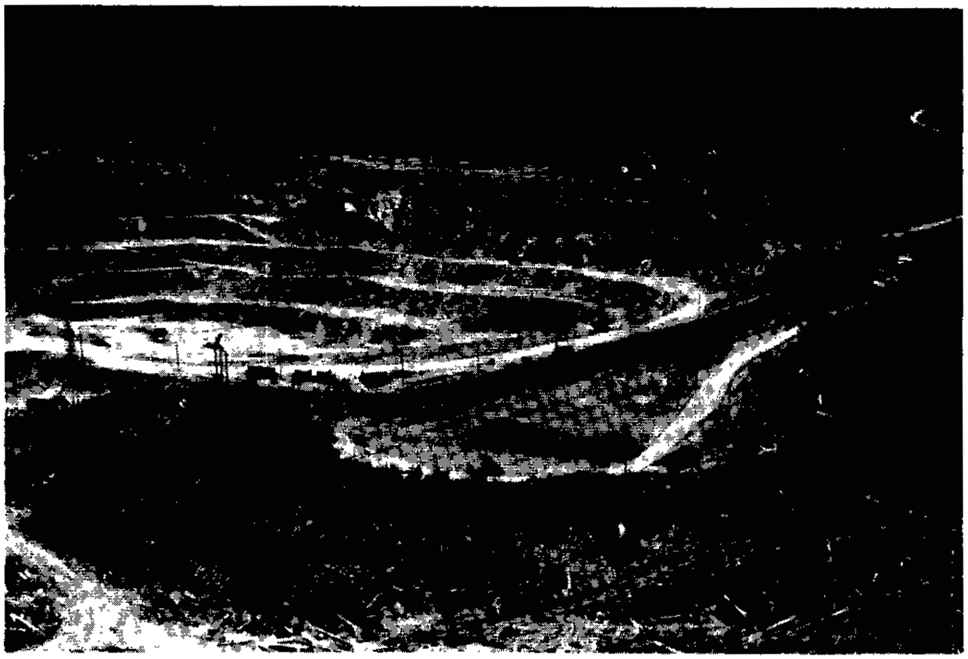

Plate X. Open pit in 1963. Buildings are on dam built to divert Draw Creek from pit area.

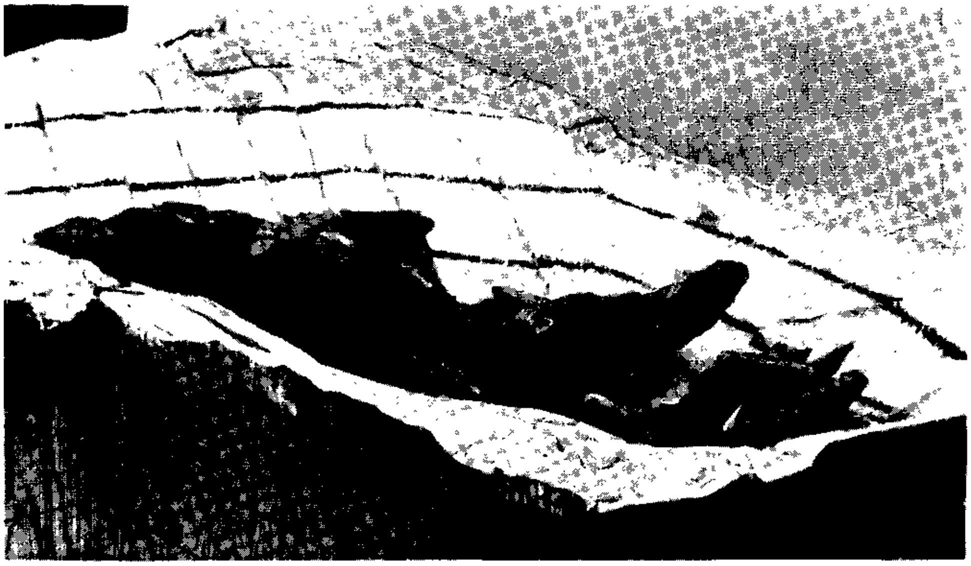

Plate XI. Model of Brynnor open-pit orebody, looking southwest.

Plate XII. Model of Brynnor open-pit orebody, looking south.

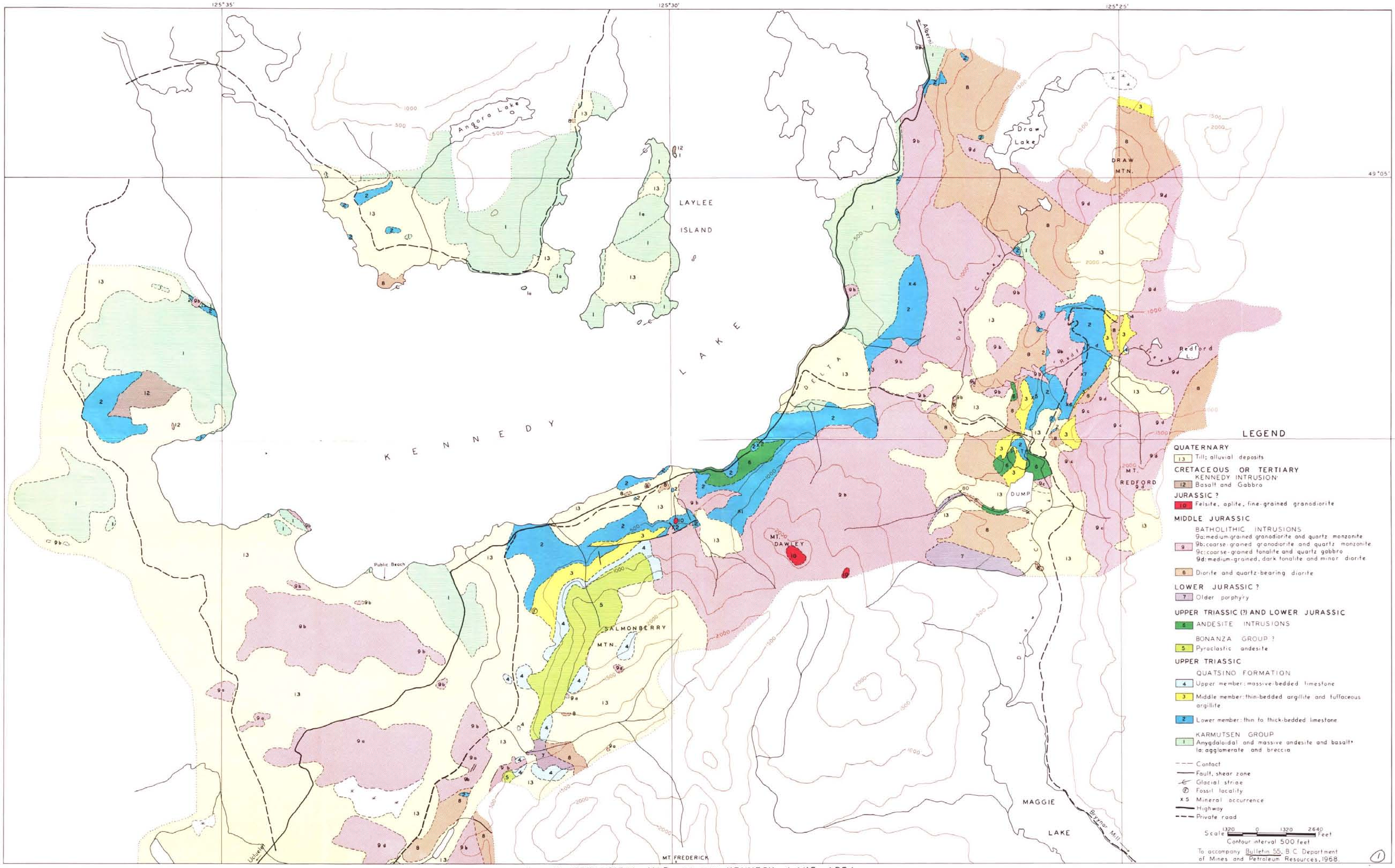


Figure 2: GEOLOGICAL MAP OF THE KENNEDY LAKE AREA

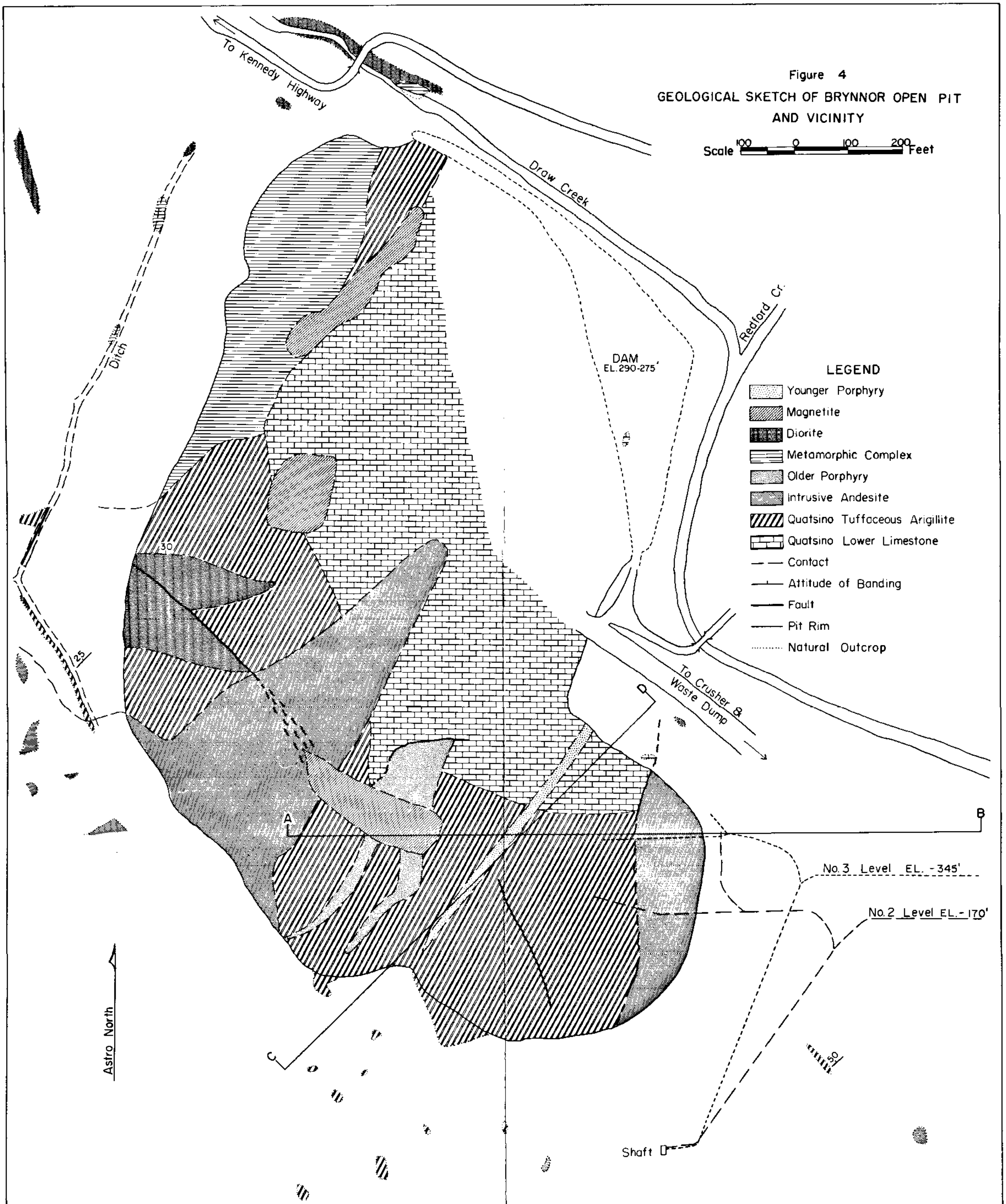
Figure 4
GEOLOGICAL SKETCH OF BRYNNOR OPEN PIT
AND VICINITY
Scale
100
0
100
200
Feet
To Kennedy Highway
Draw Creek
Redford Cr.
DAM
EL. 290-275'
Ditch
To Crusher & Waste Dump
LEGEND
Younger Porphyry
Magnetite
Diorite
Metamorphic Complex
Older Porphyry
Intrusive Andesite
Quatsino Tuffaceous Arigillite
Quatsino Lower Limestone
Contact
Attitude of Banding
Fault
Pit Rim
Natural Outcrop
30
25
50
A
B
C
D
No. 3 Level EL. -345'
No. 2 Level EL. -170'
Shaft
Astro North

#55 (2)