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GEOLOGY
of the
DUNCAN LAKE AREA
LARDEAU DISTRICT
BRITISH COLUMBIA

by

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Geology of the Duncan Lake Area, Lardeau District, British Columbia

SUMMARY

1. The Duncan Lake area includes about 200 square miles in southeastern British Columbia containing Duncan Lake and the north end of Kootenay Lake.

2. The area straddles the Purcell trench, the western part lying along the eastern slope of the Selkirk Mountains and the eastern part lying in the Purcell Mountains.

3. Rocks of the area form part of the Kootenay arc, a curving belt of complexly deformed sedimentary, volcanic, and metamorphic rocks extending from Revelstoke southeast, south, and southwest across the International Boundary.

4. This report is primarily a study of the structure and the structural setting of lead-zinc deposits developed recently at the Duncan mine.

5. Rocks in the area belong to the Hamill and Lardeau Groups and are highly deformed sedimentary and volcanic rocks. The lithology and stratigraphy are summarized in the table on page 32.

6. They are very similar to rocks of the Ferguson area 50 miles to the northwest, with which they have been correlated. Many of the formations can also be readily correlated with rocks in the Salmo area, 150 miles to the south, and the Rogers Pass area, 100 miles to the northwest. Though no fossils have been found in the Duncan Lake area, the rocks are known to be pre-Mississippian, and the Badshot Limestone, a prominent marker in the area, elsewhere contains Lower Cambrian fossils.

7. Sills of felsite which are common in the southwestern part of the area, dykes of lamprophyre, and small sill-like bodies of amphibolite constitute the only intrusive rocks.

8. Within the area the grade of regional metamorphism increases from low grades characteristic of the northwesterly trending part of the arc northwest of Duncan Lake to garnet and higher grades characteristic of rocks along Kootenay Lake. The garnet isograd trends north from near the northwest corner of Kootenay Lake to the northern end of Duncan Lake.

9. Complex folds dominate the structure of the area. Several stages of folding are recognized, which probably all belong to one orogenic period, thought to be Mesozoic.

10. The oldest folds recognized, called Phase I folds, are isoclinal and plunge at low angles to the north. Most of these folds cannot be seen, and are reconstructed from studies of the distribution of rock sequences and the mapping of formations. The limbs and axial planes of these folds are curved and have been folded by Phase II folds.

11. The principal Phase I folds are, from east to west, the Howser syncline, the Duncan anticline, the St. Patrick syncline, and the Meadow Creek anticline (*see* Fig. 16, p. 62).

12. Phase II folds are more open than Phase I folds. The folds plunge mainly to the north and northwest at angles as great as 30 degrees, but most plunge between north 15 and 25 degrees west at 5 to 10 degrees. Phase II folds are clearly visible in many outcrops and are defined by the layering of the rocks and by the attitudes of the formations.

13. Strike faults, many of which are parallel to the cleavage planes in Phase II folds, are common. Some faults are related and subordinate to the folding; others are superimposed on it.

14. The most important mineral deposits in the area are relatively low-grade zones of lead-zinc mineralization that have been developed recently but not mined. They are referred to as the Duncan type of deposit, from the Duncan mine.

15. Essentially all the deposits of the Duncan type are in the Badshot Formation on the Duncan anticline. Some 15 to 20 mineralized zones of this type are known within the map-area.

16. They consist of pyrite, sphalerite, galena, and minor pyrrhotite disseminated in dolomite and siliceous dolomite. They are lenticular zones with gradational but, in general, well-defined margins. The attitude is essentially parallel to that of the enclosing formations; the largest dimension is parallel to the strike, and the intermediate dimension is parallel to the dip. The longest axes of the mineralized zones plunge at low angles to the north, parallel to the axes of Phase II folds. The greatest plunge length found so far is more than 3,000 feet, the height may be as great as 500 feet, and the thickness is generally a few tens of feet but may be as much as 100 feet. The average grade is less than 10 per cent combined lead and zinc, and the grade of the zinc is greater than that of the lead.

17. Dolomite and siliceous dolomite in which the Duncan type of deposits are found are dark-grey rocks with mottled, flecked, and banded textures resulting from deformation. The mineralized zones appear to be structurally controlled replacements of the dolomite. Relatively thick and continuous dolomite layers on the Duncan anticline have localized mineralization.

18. The only production from mines in the area has been from a number of silver-rich lead-zinc deposits of various types. Total production from the area amounts to 2,100 tons from five properties. Four of these properties are veins and replacements in limestone and dolomite. The fifth property contains quartz veins carrying tetrahedrite.

CHAPTER I.—INTRODUCTION

Duncan Lake is in the southern part of the Lardeau district of southeastern British Columbia, a few miles north of the north end of Kootenay Lake. The Duncan Lake area of this report includes about 200 square miles of country containing Duncan Lake and the northern end of Kootenay Lake (*see* Fig. 1). The principal communities are Lardeau and Argenta on Kootenay Lake, Meadow Creek and Marblehead 10 miles to the north, and Howser on Duncan Lake. The nearest town is Kaslo, some 15 miles south of the southern edge of the map-area. The area is reached by road from the south via Kaslo and from the north through Revelstoke via Arrowhead and the Arrow Lakes ferry.

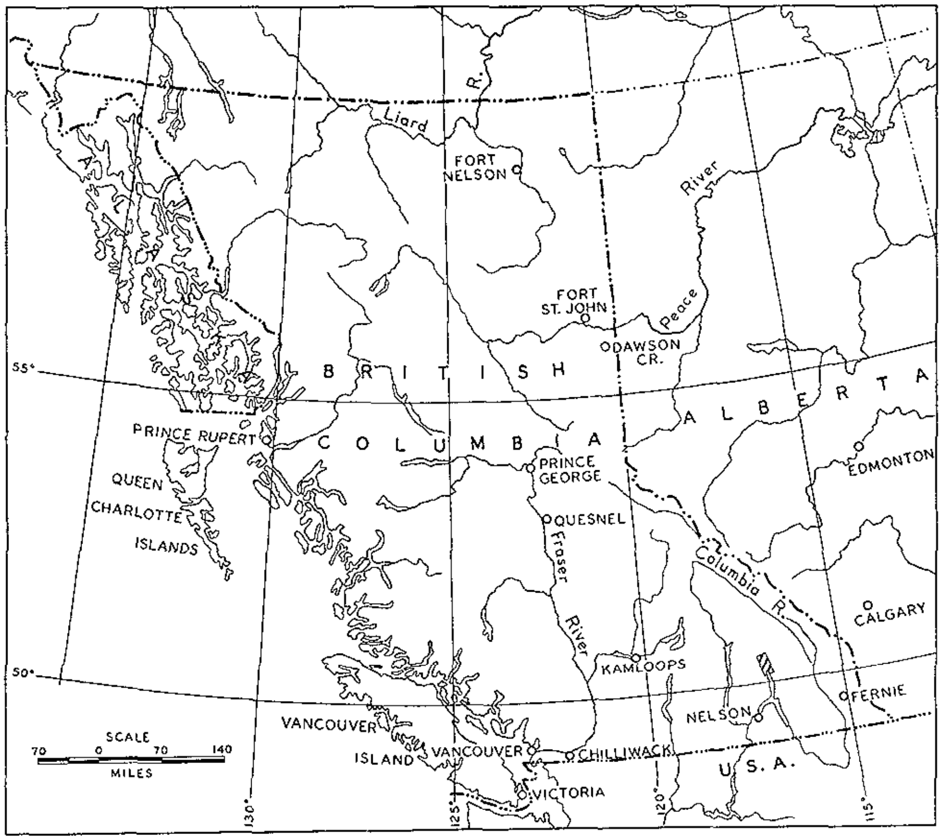

Figure 1. Index map showing location of the Duncan Lake area.

The Duncan Lake area straddles the Purcell trench, a relatively straight topographic depression extending northward from beyond the International Boundary almost to the main line of the Canadian Pacific Railway, a distance of about 200 miles. The trench lies between the Purcell Mountains on the east and the Selkirk Mountains on the west. It contains the Duncan River, which flows southward through Duncan Lake into Kootenay Lake. The Lardeau River, one of the largest rivers in the district, flows southeastward from Trout Lake and joins the Duncan between Kootenay and Duncan Lakes. The Purcell Mountains rise steeply from the trench, and within the map-area are deeply incised by several creeks, the largest of which are Glacier and Hamill Creeks. The Selkirks rise somewhat less abruptly than the Purcells, and the map-area includes west of the trench only relatively low rock benches and ridges and not the Selkirk Mountains themselves.

Geologically the Duncan Lake area is within the Kootenay arc, a curving belt of highly deformed sedimentary, volcanic, and metamorphic rocks extending southeast from near Revelstoke, south along Kootenay Lake, and south and west across the International Boundary (*see* Fig. 5). The Kootenay arc is a structural belt bounded somewhat arbitrarily on the east by quartzites that lie beneath a limestone formation known as the Badshot Limestone. Rocks within the arc in general dip steeply and are bowed around the eastern margins of two granitic masses, the Nelson batholith in the south and the Kuskanax batholith in the north. A broad anticlinorium lying east of the arc occupies most of the Purcell Mountains. The Shuswap terrane, a vast gneissic complex, lies to the west.

The Kootenay arc is of relatively great economic importance in British Columbia, because mines within it have produced a large proportion of the silver, lead, zinc, and tungsten of the Province and substantial quantities of gold and copper. Continued studies have shown that most of the mineral deposits in the arc are controlled or otherwise influenced by the structure of the enclosing rocks. A knowledge of the structure is important to an understanding of the mineralizing processes and to the exploration and efficient mining of the deposits. Consequently, one of the main purposes of this study has been to determine the structure of the area, and, as a result, not only local structures have been studied, but also structural patterns of significance throughout the arc and beyond it have been determined. Both the details and the regional pattern are useful in prospecting and exploration.

The Duncan Lake area contains Palæozoic sedimentary and volcanic rocks of a low to medium grade of regional metamorphism that have been deformed by multiple folding. Patterns of folding found in the Duncan Lake area are characteristic of the structure along the arc to the south and probably also to the northwest. The area is in a part of the arc where the regional strike changes from almost due north along Kootenay Lake to northwest, west of Duncan Lake. Within the Duncan Lake area the metamorphic grade rises from chlorite-muscovite, typical of rocks in the northwesterly striking part of the arc, to garnet grade in the southern and eastern part of the area and to the south along Kootenay Lake.

Prospecting in the district began many years ago, and relatively small quantities of high-grade silver ore have been produced from mines within the map-area. Recently, large deposits of low-grade lead and zinc disseminated in dolomite have been developed, but they have not yet been mined. These deposits are economically the most interesting in the area, and the present work has been aimed at outlining their geological setting.

TOPOGRAPHY AND ACCESS

The topography of the Duncan Lake area is dominated by three major valleys—the Duncan Valley, which contains Duncan Lake, Duncan River, and the north end of Kootenay Lake, and the tributary valleys of the Lardeau River and Meadow Creek. The Duncan and Lardeau Valleys are separated by Howser Ridge, which rises gently northward from near Howser to alpine meadows surrounding Howser Knob, a 7,000-foot summit 9 miles north of Howser. The Lardeau and Meadow Creek valleys are separated by a low ridge called Lardeau Ridge, which extends from Marblehead to near Goldhill. West of the valley of Meadow Creek and east of the Duncan Valley, the slopes rise steadily to alpine summits at elevations of about 8,000 feet.

Below 6,500 feet the hills and valleys are covered by trees, mainly hemlock, fir, tamarack, cedar, and spruce of moderate size. Because of forest fires, few stands of very large trees remain, and the most extensive stands west of Meadow Creek and Kootenay Lake are being logged. In general, where the trees are of moderate and of large size the underbrush is light. Some areas that have been burned within the last 15 or 20 years, such as the east slope of Howser Ridge and the bench west of Lardeau, are a thick tangle of blown-down trees and underbrush. Older burns are a jungle of closely spaced small conifers. Above elevations of 6,500 feet the country in general is open with grassy meadows, rocky summits, and clumps of alpine trees.

Despite the timber cover, the area is generally well suited for geological study. Although major valleys contain areas of extensive till or gravel and some of the more gentle slopes have only scattered outcrops, in general outcrops are abundant. Cliffs and canyons at the lower elevations and rocky summits above timberline provide excellent exposures. Deep valleys that cross the structure, particularly those east of the Duncan Valley, give natural cross-sections, some with a relief of more than 4,000 feet.

Most of the area is readily accessible by roads and trails. The main road from Kaslo passes through Lardeau to Howser and through Goldhill to Trout Lake beyond the map-area. Branch roads to Argenta cross the Duncan River 4 miles north of Lardeau and at the south end of Duncan Lake. Mining-roads from the Argenta road from the south end of Duncan Lake extend to the Duncan mine on the peninsula on the east side of Duncan Lake, 2 miles up Glacier Creek to the adit of Lardeau Lead & Zinc Mines, and to the St. Patrick mine on the ridge north of Hamill Creek. Logging and forest-protection roads are in use along Howser Ridge to Howser Knob and on the eastern slopes of Meadow Mountain. Most valleys contain old mining access trails, many of which are in moderately good condition because of maintenance from time to time by prospectors and the British Columbia Forest Service. The valley of Clint Creek, which contains only vestiges of an old trail, is quite inaccessible, but alpine country to the south is easily reached from a relatively new forest-protection road which climbs to an elevation of 6,500 feet at the head of Kootenay Joe Creek less than 2 miles south of the south edge of the map-area. The condition of roads and trails varies from year to year, depending on the extent to which they are used and maintained. All roads on which vehicles could drive in 1962 are shown on Figure 3. Some require four-wheel drive. Disused roads are shown as trails.

GLACIATION

Specific studies of the glacial features of the area have not been made in the present work, but the effects of glaciation are obvious, and some of the more outstanding features are described here. Probably the most striking features are the scoured rock walls of the major valleys and the rounded, streamlined shapes of rock ridges and outcrops. Quartzites and locally limestones form resistant ridges with gentle slopes facing upstream to the north and northwest and abrupt lee slopes facing downstream. Most commonly these ridges are elongate parallel to the axes of north-plunging folds, the cross-sections of which are well displayed in the lee cliffs. Glacial scour has accentuated the structural grain of the country, making it particularly noticeable on air photographs.

Deposits of till are common on the more gently sloping valley walls and are up to 50 to 60 feet thick in some of the valley bottoms, particularly in Meadow Creek. Morainal ridges, some of which are 30 to 40 feet high, are present at a number of places and are particularly noticeable on the southwest slope of the Lardeau Valley near Goldhill at elevations of 3,000 to 4,000 feet, and on the eastern slope of Howser Ridge west of the Duncan mine. Till and outwash deposits in the main valleys give evidence of a complex history of glacial retreat. No attempt has been made to reconstruct the glacial history, but among prominent glacial features in the main valleys are the following:—

(1) A prominent delta on which the community of Howser has been built extends into the west side of Duncan Lake. It is composed of coarse sand and gravel. The upper surface is flat and at an elevation of about 2,050 feet and locally the flat part is covered by an upper layer of silt and clay. The toe of the delta has been slightly modified by currents in Duncan Lake, which have cut away the upstream side of the delta and deposited sand in a spit at Howser. The delta appears to have been built into a body of water which stood at a level considerably higher than that of the present Duncan Lake by a stream flowing eastward from the Lardeau Valley across the lower part of Howser Ridge.

(2) A terrace of coarse sand and gravel at an elevation of about 2,050 feet is present on both sides of the Lardeau Valley between Marblehead and Goldhill. Exposed material composing the terrace is stratified and more or less well-sorted sand, gravel, and minor silt. Only remnants of what was probably a more extensive terrace can be found, and it seems probable that the terraces represent the eroded remains of an outwash plain which at one time filled all or a large part of the Lardeau Valley. A river running on this plain may have spilled eastward through the pass containing the road to Howser and produced the Howser delta. It is significant that no terraces like the one in the Lardeau Valley are found in the Duncan and Meadow Creek valleys. It is also significant that another pass at about the same elevation cuts through bedrock on Howser Ridge due west of the outlet of Duncan Lake but has no delta east of it. Sand on top of the terrace in Lardeau Valley stands a few feet above the west end of the bedrock pass. Possibly ice occupied the lower Duncan and Meadow Creek valleys at the time the Howser delta was being formed.

(3) Unconsolidated deposits have been drilled at the site of the Duncan dam (*see* Fig. 3) to a depth of about 500 feet below the present gravel surface. The drilling shows that beneath a relatively thin surface layer of gravel is a thick deposit of silt and minor clay with lenses of sand and gravel within and beneath it. These deposits are presumed to have been laid down since glacial ice withdrew from the Duncan Valley. Refractive seismograph surveys along two profiles—one at the axis of the proposed dam and the other between the bridge at the outlet of Duncan Lake and the first outcrops north of the Glacier Creek canyon—were made in the damsite investigations. The surveys show that the deepest point of the rock floor beneath the unconsolidated material is no higher than 600 feet above sea-level, and that at the damsite there is probably a canyon-like slot in the bedrock surface below an elevation of about 1,200 feet above sea-level.

HISTORY OF EXPLORATION

Transportation has been one of the most important factors affecting the development of mining properties in the Duncan Lake area. For many years the Duncan and Lardeau Valleys were accessible only by boat and railway. The Canadian Pacific Railway from Lardeau to Gerrard on Trout Lake was completed in 1902, and trains were operated in connection with a steamship service on Kootenay Lake. In 1942 the railway was converted to a motor-road. In 1953 a mining access road from Kaslo to Lardeau and from Gerrard to Trout Lake was constructed by the British Columbia Department of Mines, and this, together with the converted railway, formed the first trunk road through the Duncan Lake area. Railways in addition to the Canadian Pacific were planned in the early days but were never completed. Old grades from Argenta and Marblehead to Howser, constructed in 1899, are still used in part as motor-roads.

Mining and exploration in the Duncan Lake area has centred around half a dozen properties, all of which were discovered between 1890 and 1900. The Lavina property, on the western summit of Lavina Ridge, was the first to come into prominence. High-grade lead ore containing silver was shipped first in 1901 by rawhiding it down a steep trail into Hamill Creek. Between 1900 and 1907 considerable work was done on the Lavina and on the nearby Argenta property on the north slope of Hamill Creek. A wagon-road on bridges and rock ledges was built through the box canyon of Hamill Creek, and a 10-drill Allis-Chalmers water-driven compressor was installed beside the creek for the Argenta property.

Between 1896 and 1907 lime was produced for flux for the Hall smelter in Nelson from a small quarry on Kootenay Lake half a mile north of Lardeau. In 1908 production of building-stone from marble quarries just north of Marblehead was started by Canadian Granite and Marble Company, Limited, of Edmonton. The stone, known as " Kootenay " marble, was quarried until about 1930 and was used at first for building and decorative purposes and in later years for monuments. The courthouse, city hall, and Bank of Commerce building in Nelson are faced with Kootenay marble.

In 1917 the Lavina property was operated by leasers, and between 1924 and 1927 the property was developed by Ed. Nordman and associates, who shipped a few tons of ore in 1927. In 1919 a shipment of ore was made from the St. Patrick mine, a silver-lead property 1½ miles southwest of the Argenta property. The St. Patrick was owned by Jean Brochier, of Kaslo, who had carried on exploration on the property for a number of years. In the early twenties the Surprise group on Glacier Creek, owned by F. A. Devereaux, of Victoria, attracted attention, and in 1923 and 1924 shipments of sorted silver ore were made by Spokane interests. The ore is tetrahedrite in quartz, and some difficulty was encountered in sorting because of the friable character of the tetrahedrite.

Judging from published accounts, there was very little mining or exploration in the Duncan Lake area in the thirties. Leasers made shipments from the St. Patrick in 1937 and 1938.

The name of Joe Gallo,* of Howser, is associated with much of the recent prospecting and promotion of properties in the Duncan Lake area. Mr. Gallo and associates obtained the Surprise, and between 1946 and 1954 produced more than 1,200 tons of silver ore. Near Duncan Lake relatively low-grade occurrences of lead and zinc in limestone were known for many years. Showings on the peninsula east of the lake were located in the 1920's as the Lakeside and Amato-Ruby groups, and some work was done on them by J. S. Hinks and W. C. P. Heathcote, who owned farm land on Duncan Lake. To the south, in the same belt, showings on Glacier Creek were known from the earliest days of prospecting (*see* Telfer, 1961). About 1950 Joe Gallo and associates relocated this group of properties as the J.G. group, and since that time several companies have carried on exploration under option from the owners. In 1951 and 1952 Lardeau Lead & Zinc Mines Ltd. drilled on the Lakeshore showings and drove an exploratory adit on the showings on the north slope of Glacier Creek. Exploration was continued by Berens River Mines Limited in 1953 and by The Bunker Hill Company of Kellogg, Idaho, in 1955 and 1956. The Consolidated Mining and Smelting Company of Canada, Limited, began exploration on the claims in 1957, and since then has been successful in de-

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* Mr. Gallo died February 22, 1964, at the age of 74.

veloping a large tonnage of low-grade lead-zinc ore on the peninsula. In 1960, following an extensive geological and diamond-drill programme, a crosscut and exploratory drift were driven 35 feet above lake-level in what is now known as the Duncan mine. Although this exploration indicates the presence of large mineralized zones, production has not been undertaken and exploration has been discontinued. The property is now owned by the Consolidated company, and it is expected that in due course lead and zinc will be produced. Exploration on the Duncan property led to extensive prospecting, mainly by the Consolidated company, to the north and south for lead-zinc deposits in the same geological setting as those on the Duncan property. Several showings were found to the south between Glacier Creek and the northern edge of the Fry Creek batholith. Most of these showings were rediscoveries of very old prospects. Two properties, the Mag northwest of Lavina Lookout and the Sal on Mount Willet, were drilled in 1960 and 1961, but the results were not encouraging.

GEOLOGICAL WORK

The Geological Survey of Canada has made three regional geological studies which include the Duncan Lake area—one between 1903 and 1907, the second between 1917 and 1926, and the third between 1953 and 1957. The early exploration done by R. W. Brock, mainly in 1904 and 1907, is largely of historic value. In the light of the present understanding of the complex structure of the area, it is interesting to note that Brock recognized " a low anticlinal arch with a slight northward plunge" (Brock, 1908, p. 86) across the head of Kootenay Lake. He also contrasted the apparent simplicity of this structure and very tight folding nearby. The geological survey between 1917 and 1926 was started by M. F. Bancroft and completed with the help of J. F. Walker and H. C. Gunning in 1926. The results of this work are published in Memoir 161, in which the major stratigraphic subdivisions are outlined and some of the larger structures are described. One of the most important formations mapped was the Badshot Limestone, which forms a series of high peaks extending northwest from the head of Duncan Lake. In 1928, after working south from Duncan Lake, Walker (1928) published a map showing the trace of the Badshot Limestone south along the east side of Kootenay Lake to Crawford Bay. Although this area has been restudied (*see* Rice, 1941), only minor revisions of the geological map have been made since 1928.

Recent mapping of the Lardeau East Half map-area by J. E. Reesor, in the southwest corner of which is the Duncan Lake area, has been published only as a preliminary map (12-1957). This map and marginal notes give little indication of the complexities of the structure of the Duncan Lake area, although Reesor was aware of the complex repetition of the Badshot Formation along the northern part of Kootenay Lake.

The present study is an outcome of a reconnaissance made by the writer and C. G. Hewlett in 1956. In this reconnaissance, striking similarities between the stratigraphy of the Salmo area 150 miles to the south and limestone-schist sequences along Duncan Lake were noted. Repetitive folding of the Badshot and adjacent formations was suggested, similar to that found in the Salmo area. The possibility of this type of structure and the presence along Duncan Lake of scattered lead-zinc mineralization of a type being mined in the Salmo district pointed to the economic significance of the region and the need for detailed structural studies. Before mapping could be started, The Consolidated Mining and Smelting Company of Canada, Limited, had shown the importance of the Duncan lead-zinc deposits and had obtained valuable information on the stratigraphy and structure of the district. The present study was made in August of 1960 and 1961 and June, July, and August of 1962. Mapping was done on a scale of 2,000 feet to the inch on base maps prepared from enlargements of 1:40,000 scale manuscript topographic maps made by the Dominion Topographic Survey from high-level (R.C.A.F.) air photographs. Plotting was done with the aid of British Columbia Government air photographs, barometer readings, compass resections, and compass and pace traverses. The magnetic declination was taken as 23½ degrees east of north. Plane-table geological maps of the Consolidated company on a scale of 1 inch to 100 feet were used for structural studies of areas near the Duncan mine.

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Able assistance in the field was given in 1960 by D. F. Rebagliatti, in 1961 by A. J. Sinclair, D. J. Templeman-Kluit, and A. Armour-Brown, and in 1962 by R. V. Kirkham, John Fairley, and John Brock. Sinclair and Kirkham, graduate students in geology at the University of British Columbia, contributed many ideas in the analysis of the geological problems of the area.

The writer is indebted to the residents of Howser, particularly to Joe Gallo and William Clark, for help with the field work in a number of ways. Geologists and prospectors of The Consolidated Mining and Smelting Company of Canada, Limited, particularly J. Richardson, T. W. Muraro, and A. B. Mawer, were very helpful in discussing geological problems and in providing maps and geological data obtained in their exploration and prospecting.

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CHAPTER II.—GENERAL GEOLOGY

The Duncan Lake area contains complexly folded sedimentary and volcanic rocks in a low to medium grade of regional metamorphism. Sills of felsite and feldspar porphyry intrude these rocks in the southwestern part of the area, and rare mafic dykes and amphibolitic sills are found elsewhere. No plutonic rocks are exposed within the area, but the northern edge of the Fry Creek batholith is 2 to 3 miles south of the southern edge of the area, and granitic outliers along the eastern margin of the Kuskanax batholith are less than 10 miles to the west.

The sedimentary and volcanic rocks in the Duncan Lake area belong to the Hamill Group, Badshot Formation, and Lardeau Group named by Walker and Bancroft (1929) in their regional mapping of the Lardeau map-area. Recent studies in the Kootenay arc have subdivided these rock units and defined them more accurately. The formations found in the Duncan Lake area are lithologically very similar to those of the Ferguson area 30 miles northwest of Duncan Lake, and many formational names used in this report originated in the Ferguson area (*see* Fyles and Eastwood, 1962). The following table shows the formations, map units, and general lithologies of rocks in the Duncan Lake area:—

TABLE OF FORMATIONS

Group	Formation	Map Unit	Description
			Mafic dykes. Mainly sills of felsite, aplite, fine-grained syenite.
	Intrusive contacts.		
Lardeau.	Broadview.	6	Green and grey micaceous quartzite, greywacke, grit, and fine-grained mica schist.
	Jowett.	5	Fine-grained chlorite schist and feldspar-chlorite schist.
	Sharon Creek. Ajax. Triune.	4	4(*c*) Dark grey to black argillite. 4(*b*) Massive grey quartzite. 4(*a*) Grey and black quartzite and argillite.
	Index.	3	Upper Index: 3(*d*) Feldspar-chlorite schist. 3(*c*) Green mica schist and garnet mica schist; minor lenses of grey schist and limestone.
			Lower Index: 3(*b*) Creamy-white and grey fine-grained limestone, micaceous limestone, brownish quartzite, and fine-grained grey and green schist. 3(*a*) Grey and dark-grey fine-grained mica schist, calcareous dark-grey mica schist, and dark-grey limestone; locally grey garnet and staurolite-mica schists.
	Badshot.	2	Grey and white crystalline limestone, dolomite, and siliceous dolomite.
	Mohican.	2	Interlayered limestone or dolomite and green or grey mica schist; porphyroblasts of garnet, chloritoid, or biotite in higher metamorphic grades.
Hamill.	Marsh-Adams.	1	Grey and brown micaceous quartzite and mica schist; white quartzite and minor brown-weathering limy schist.

Correlations both within the Duncan Lake area and with rocks of the Ferguson area are based on lithology and sequences of rock types. For most of the formations there is little doubt about correlation, but in the upper part of the Index Formation it has not been possible to be certain of the stratigraphic positions of some of the limestones, quartzites, and volcanic rocks. Also, in the highest grades of metamorphism grey garnet mica schists are found in both the Mohican and Lower Index Formations, and where the Badshot is not present it is not possible to distinguish with certainty grey schists of the Index from those of the Mohican Formation.

The structure of the Duncan Lake area is exceedingly complex, and a full understanding of the structure depends on a complete knowledge of the stratigraphy. Although this study was started with considerable background experience in the Kootenay arc, details of the structure and stratigraphy were worked out in the Duncan Lake area only by careful mapping of rock units and analysis of major and minor structures. The determination of the structure and stratigraphy went on together, and several remaining problems depend for their solution on a further knowledge of either the structure or the stratigraphy. Rock sequences are described in this chapter as stratigraphic sequences, but stratigraphy in the strictest sense is not found in the Duncan Lake area. The observed interlayered rock units are commonly not equivalent to sequences of strata as they were originally laid down. Original thicknesses of formations are unknown because the observed thicknesses can be converted to original thicknesses only through a complete knowledge of the deformational processes. Though many aspects of the structure are known, the process of deformation is very poorly understood.

SUBDIVISIONS OF THE MAP-AREA

The Duncan Lake area contains complex folds which plunge to the north at low angles. The oldest rocks are in the southern and eastern part of the area, and the youngest rocks are in the northern and western part. In general, the areas in which rocks of the Hamill Group are exposed are anticlinal and those in which the Lardeau Group are exposed are synclinal—the trace of the Badshot and Mohican Formations outlines the folds. On the basis of these generalizations, several structural subdivisions of the map-area may be defined to facilitate descriptions of the general geology. The structures themselves are described in Chapter III.

The five subdivisions of the map-area are as follows:—

(1) *Eastern Belt.*—Outcrop areas of the Badshot, Mohican, and Marsh-Adams Formations along the eastern edge of the map-area are referred to as the eastern belt. The Badshot Formation in the eastern belt forms the south-eastern extension of the famous Lime Dyke (*see* Walker and Bancroft, 1929), the name given to a spectacular row of tooth-like limestone peaks extending 50 miles northwest from near the northern end of Duncan Lake. In the Duncan Lake area the Badshot Formation does not have a dyke-like topographic form, largely because the Badshot is lenticular and pinched out in much of the eastern belt.

(2) *Howser Syncline.*—The eastern belt is followed on the west by a wide synclinal belt of rocks mainly of the Lardeau Group, here called the Howser syncline.

(3) *Duncan Anticline.*—West of the Howser syncline is a narrow persistent anticlinal belt of rocks of the Marsh-Adams, Mohican, Badshot, and Lower Index Formations. This has been named the Duncan anticline by geologists of the Consolidated company after the Duncan mine. A series of isoclinal folds, subsidiary to this anticline, lie along its western flank.

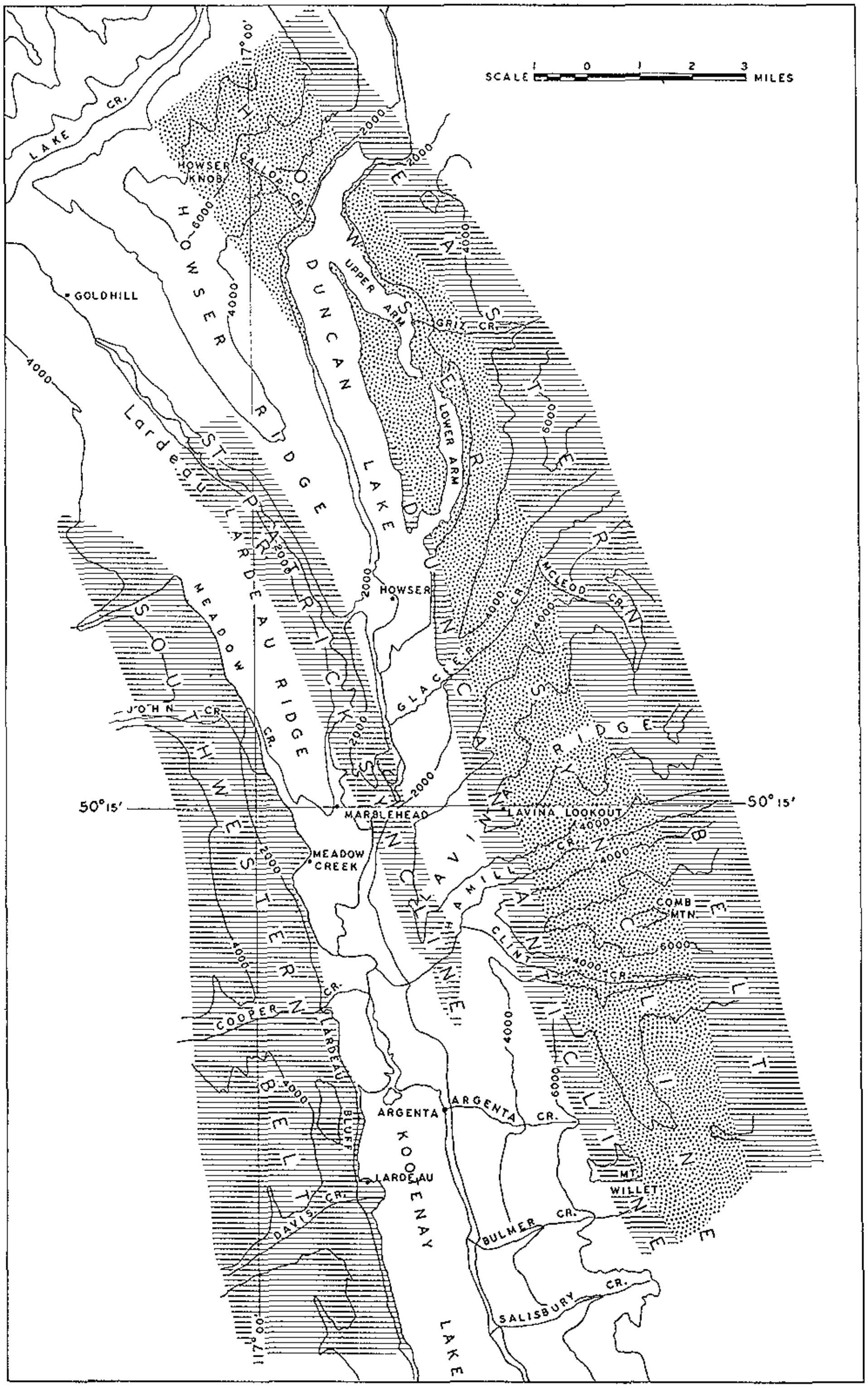

Figure 2. Map showing names and subdivisions of the map-area.

(4) *St. Patrick Syncline.*—The Duncan anticline and subsidiary folds on its western flank are followed by a belt of rocks in which the structure is poorly known, but which in general is synclinal and is here referred to as the St. Patrick syncline, from the St. Patrick mine north of Hamill Creek. Rocks in the St. Patrick syncline largely belong to the Lardeau Group, and are exposed northward from near the mouth of Clint Creek along the lower part of Howser Ridge and along the western slope of Howser Ridge to Lake Creek.

(5) *Southwestern Belt.*—Southwest of the valley of Meadow Creek and the north end of Kootenay Lake is an area in which only the general characteristics of the structure are known. It is referred to as the southwestern belt and contains in part a large fold called the Meadow Creek anticline. This is a complex, dominantly recumbent anticline, parts of which are exposed along the lower slopes on both sides of the head of Kootenay Lake and lower Duncan Valley, and in bluffs on Lardeau Ridge northwest of Marblehead.

The complex folds found in the Duncan Lake area have developed from the movement of rock masses over an extended period of time and in response to varying local and regional stresses. Several phases of the deformation are recognized. The two most prominent, which appear to be the oldest and to have regional extent, are referred to as Phase I and Phase II. Structures of the first phase of deformation, called Phase I structures, are mainly isoclinal folds. Phase II structures are more open folds and related shears. The anticlines and synclines named in the preceding paragraph are Phase I folds. Because they are complex structures in themselves, and because they have been folded and faulted by Phase II structures, they can be defined only in general terms. The general areas covered by these structures are shown on Figure 2.

HAMILL GROUP

The Hamill Group was named by Walker and Bancroft (1926) from exposures of quartzites along the upper part of Hamill Creek. The group, estimated to be several thousand feet thick, outcrops widely east of the Duncan Lake map-area, where it forms some of the higher peaks of the Purcell Mountains. Only the uppermost part of the Hamill Group is exposed within the area. It consists of several hundred feet of grey and brown micaceous quartzite and quartz mica schist with interbeds of white quartzite near the base. This heterogeneous quartzitic sequence is correlated with the Marsh-Adams Formation of the Ferguson area. It is underlain by a prominent white quartzite called the Mount Gainer Formation in the Ferguson area, and overlain by limestone and schist of the Mohican and Badshot Formations. The top of the Marsh-Adams is a good marker and has been mapped in detail. The base of the formation has not been mapped, and some areas shown on Figure 3 as Marsh-Adams contain white quartzite below the Marsh-Adams.

The Marsh-Adams Formation is exposed along the eastern edge of the map-area and is repeated several times to the west, principally in the cores of the Duncan and Meadow Creek anticlines. The most accessible sections of the Marsh-Adams Formation are along the Lardeau Bluff, west of Marblehead, and on the eastern side of the southern part of Duncan Lake, but all these sections are complicated structurally. The simplest well-exposed sections are on Mount Willet and the southwest face of Comb Mountain. These sections are very similar lithologically and are thought to be as complete as any within the area. The section on Comb Mountain is summarized in the following table:—

Formation	Approximate Thickness (Ft.)	Lithology
Mohican (basal member).	2–10	Buff-weathering, white, micaceous crystalline limestone.
Marsh-Adams.	20–40	Grey, blocky quartzite; locally pinkish; lenses containing visible quartz grains in limy cement near top.
	200–400	Grey to brown platy micaceous quartzite; minor grey mica schist and thin layers of white quartzite.
	50–100	Platy white quartzite.
	50–100	Interlayered white quartzite and brown micaceous quartzite and mica schist.
	30–40	Greyish-green garnet-mica schist.
	30–40	Greyish-brown micaceous quartzite and greenish mica schist, locally with brown-weathering lenses of buff limestone.
	100	Interlayered brown micaceous quartzite with some layers of white quartzite 6 to 8 feet thick.
Mount Gainer.		Blocky to platy white quartzite.

The uppermost member of the Marsh-Adams Formation is a grey blocky to platy quartzite a few feet to a few tens of feet thick. Though dominantly grey, it may have a brownish cast and in the eastern belt may contain pinkish-white lenses. Greyish-brown micaceous interlayers are found in some sections. Lenses with visible quartz grains in a rusty-weathering calcareous cement are present near the top of the member in the eastern belt and locally on the Duncan anticline. These lenses in the eastern belt and on Comb Mountain are commonly cross-bedded.

The micaceous quartzite below the uppermost member contains sections with well-defined light-grey to brownish beds of quartzite in mica schist and quartz mica schist. The beds are a fraction of an inch to a few inches thick and display many clearly defined minor structures, particularly folds (*see* Plate XVI).

Platy white quartzites form a well-marked member on the Duncan anticline, on Comb Mountain, and in the eastern belt. They are found only locally in the Meadow Creek anticline, particularly on the north side of Davis Creek, near the mouth of Salisbury Creek, and on the east side of Meadow Creek a few miles from Marblehead. This white quartzite appears to be the lowest member of the Marsh-Adams Formation exposed in the Meadow Creek anticline.

Mica schist and garnet mica schist with interbeds of white quartzite and a thin calcareous layer underlie the platy white quartzite. The mica schists are dominantly brownish, but near the calcareous beds they have a greenish cast. The calcareous beds are cream coloured, brownish, and brown-weathering limestones a few inches thick alternating with mica schists and micaceous quartzites in a zone a few feet to a few tens of feet thick.

Micaceous quartzites of the Marsh-Adams Formation seen under the microscope contain, in addition to quartz, muscovite, and biotite, subhedral crystals of tourmaline, rounded grains of apatite and zircon, and scattered pyrite, pyrrhotite, or magnetite. Plagioclase is present as poorly defined grains between quartz crystals in some thin-sections. Porphyroblasts are biotite, garnet, and locally epidote. The quartz has a mosaic texture, and only rarely do aggregates of quartz crystals show the vague outlines of original rounded sedimentary grains. In the sections studied, these grains are 2 to 3 millimetres across, and the crystals themselves are less than half this size. Where sedimentary grains can be distinguished, for example in the eastern belt north of Glacier Creek, the quartz crystals are elongate with a shadowy extinction and incipient planes of parting which form poor rock cleavage.

This cleavage contains most of the mica plates, which are concentrated in layers cut by the cleavage.

Muscovite, biotite, and garnet are the most conspicuous minerals resulting from regional metamorphism of the Marsh-Adams Formation. Oligoclase has been recognized in some thin-sections. The garnet isograd defined by the first appearance of garnets in the Mohican Formation is shown in Figure 5. Rocks in the Marsh-Adams Formation east of the isograd commonly contain porphyroblasts of brown garnet. Both garnet and the micas become coarser and more conspicuous in the area south of Hamill Creek and east of Kootenay Lake, and thin-sections of quartzites from within this area do not show outlines of sedimentary grains. In general the rocks appear to be in a higher metamorphic grade, although metamorphic minerals other than those just described have not been recognized.

MOHICAN FORMATION

The name Mohican Formation is given to rocks between the top of the Marsh-Adams quartzite and the base of the Badshot Limestone. The formation is named from the Ferguson area (*see* Fyles and Eastwood, 1962, p. 17) where it is well exposed on Mohican Mountain near the type locality of the Badshot Limestone (*see* Walker and Bancroft, 1929, p. 10).

The Mohican is dominantly an interbedded sequence of limestones and schists and is quite distinct from the underlying Hamill quartzite. Walker and Bancroft placed the top of the Hamill at the base of the Badshot, thus including rocks of the Mohican Formation in the Hamill, and this division was followed in the Ferguson bulletin. In the present work it is proposed to define the top of the Hamill as the top of the Marsh-Adams Formation and to exclude the Mohican limestones and schists from the dominantly quartzitic Hamill Group.

In the Duncan Lake area the Mohican Formation has three distinct but intergrading facies—one exposed mainly in the eastern belt, another on the Duncan anticline, and a third west of the Duncan anticline. In the eastern belt the formation is composed of two parts—an upper part of grey, greenish, or brownish mica schist and a lower part which is interlayered limestone and schist. On the Duncan anticline, carbonate rocks, both limestone and dolomite, are interlayered with schist throughout the formation. West of the Duncan anticline the formation is mainly calcareous schist and is much thinner than it is to the east.

In the eastern belt the base of the Mohican Formation is marked by a bed of buff-weathering white crystalline, somewhat micaceous limestone up to 25 feet thick. This limestone may lie directly on the uppermost grey quartzite of the Marsh-Adams Formation or may be separated from it by a thin layer of brownish mica schist. The basal limestone is overlain by a succession of calcareous mica schists and white or grey micaceous limestones. Many of the schists contain coarse porphyroblasts of dark-brown biotite and locally of garnet. At the top of this limestone-schist succession is a prominent limestone 50 to as much as 200 feet thick. The limestone is white, grey and white, or buff near the top and bottom where it is somewhat micaceous. The grey and white parts resemble the Badshot Limestone, and in places it is difficult to be certain of the correlation. Locally this prominent limestone in the Mohican contains lenses of buff-weathering white, finely crystalline dolomite. Small lenses of dolomite are found on the north side of Griz Creek, and larger ones are present on Comb Mountain.

The upper part of the Mohican Formation in the eastern belt consists of fine-grained mica schist with only minor calcareous lenses. The schists are grey, greenish, and locally brown, and commonly contain porphyroblasts of chloritoid or garnet. The grey schists in places are difficult to distinugish from similar rocks in the Index Formation.

The Mohican Formation in the eastern belt ranges from a few hundred to more than 1,000 feet thick. The lower calcareous part in general is thinner than the upper grey and green schist.

On the Duncan anticline the Mohican Formation is a complex alternation of calcareous and non-calcareous rocks. The calcareous rocks are limestone and dolomite, and the non-calcareous are mica schist and minor very fine-grained micaceous quartzite. Details of the lithologic succession have been worked out by geologists of The Consolidated Mining and Smelting Company of Canada, Limited, during exploration for lead and zinc on the Duncan anticline. The succession, taken largely from their work, is tabulated below.

MOHICAN FORMATION, DUNCAN ANTICLINE, EAST OF DUNCAN LAKE

Formation	Lithology	Approximate Thickness (Ft.)
Badshot.	Crystalline limestone.	
Mohican.	Crenulated green schist, chloritoid and minor garnet porphyroblasts.	5–50
	Interlayered dolomite and fine-grained brown calcareous and micaceous quartzite.	100–200
	Grey dolomite and grey and white limestone.	50
	Greenish mica schist with biotite porphyroblasts.	10
	Brownish mica schist; minor limestone.	40–50
	White crystalline limestone.	0–10
Marsh-Adams.	Grey blocky quartzite.	

Although all the units of the foregoing table are present at many places on the Duncan anticline, complexities of the structure are such that it is not possible to be certain that some of the members are not structural repetitions of others. The proportion of dolomite in the section varies from place to place. In general there is less dolomite south of Glacier Creek than there is to the north. From Hamill Creek to the southern edge of the map-area, all the calcareous beds in the Mohican Formation are crystalline limestone, whereas near the Duncan mine essentially all the calcareous beds are dolomite.

West of the Duncan anticline the Mohican Formation consists of a few tens of feet of grey or greenish calcareous schist. In exposures on the north slope of Hamill Creek, less than a mile west of the axis of the Duncan anticline (*see* Fig. 3), the Mohican Formation comprises 15 to 30 feet of greyish mica schist with minor limy lenses. On the western limb of the St. Patrick syncline in the canyon of Hamill Creek, the formation consists of about 50 feet of grey and green mica schist with several beds of limestone, each a few feet thick. To the west, both south of Hamill Creek and between the Lardeau Bluff and Marblehead, the Mohican Formation is a few tens of feet thick and is composed of greyish-green mica schist with buff-weathering lenses of limestone an inch or so thick.

Thin-sections of schists from the Mohican Formation consist mainly of quartz and muscovite and minor chlorite, biotite, feldspar, tourmaline, apatite, and ilmenite. The feldspar is plagioclase, which generally is not twinned and has been identified in some sections as oligoclase. Porphyroblasts are commonly chloritoid or biotite, and less commonly garnet and epidote.

Lithologies of the Mohican Formation indicate an increase in the metamorphic grade toward the south and east. Garnets have not been found in the formation in the eastern belt above elevations of 3,500 feet on the north side of Duncan Lake. Also, garnets are not known on the peninsula in Duncan Lake or on Lardeau Ridge and the valley of Meadow Creek. It is considered that the rocks of the formation in all but these areas are in the garnet grade of regional metamorphism, and the garnet isograd (*see* Fig. 5) has been drawn between points where garnet first appears in the formation. Though not abundant, garnets are scattered widely. In general the schists become coarser grained toward the south and east. South of Hamill Creek they locally contain porphyroblasts of staurolite and bluish-green amphibole.

BADSHOT FORMATION

The Badshot Formation, named by Walker and Bancroft (1929, p. 10) from Badshot Mountain 50 miles northwest of the Duncan Lake area, forms a series of spectacular jagged peaks which, between Badshot Mountain and the north end of Duncan Lake, have been known for many years as the Lime Dyke. The Badshot Formation forming the Lime Dyke is a steeply dipping apparently homoclinal mass of grey blocky limestone. The limestone thins rapidly and pinches out on the steep slope northwest of the head of Duncan Lake, and occurs only intermittently to the southeast in the eastern belt of the Duncan Lake area. To the west the Badshot is repeated on the limbs of the Duncan anticline and again on subsidiary folds west of the anticline. It is found also farther to the west on the Meadow Creek anticline.

On Lavina Ridge, about 2 miles east of the lookout, the Badshot Formation consists of 250 to 350 feet of grey-weathering grey and white crystalline limestone. The upper third of the formation, exposed in the lower part of a series of cliffs, contains dark-grey quartzose beds up to 3 inches thick. On weathered surfaces they have a sandy appearance. In thin-section the quartz shows anhedral interlocking grains, some aggregates of which have vague, poorly rounded outlines resembling sedimentary grains, less than a millimetre across, in a calcareous cement.

The limestone continues north from Lavina Ridge as a series of cliffs which extend to the top of the southwest slope of McLeod Creek. It is not exposed to the north, from McLeod Creek to the north end of Duncan Lake, where the upper part of the Mohican Formation is in contact with the lower part of the Index Formation. It is concluded that the Badshot has been eliminated in this area by deformation. The Badshot limestone is exposed on both sides of the north end of Duncan Lake. On the south side it is about 60 feet thick, on the north 20 to 40 feet, and on both sides it pinches out a short distance above the lake. Northwest of the head of Duncan Lake the limestone forms a hill, elevation about 6,000 feet, standing out prominently above wooded slopes and forming the southeastern end of the Lime Dyke. The limestone on this hill is about 1,500 feet in apparent thickness—it is complexly folded and thins rapidly downward to the southeast, pinching out between elevations of 4,500 and 5,000 feet. The limestone is grey and white banded, finely crystalline, and locally contains siliceous layers which are probably near the stratigraphic top of the formation.

On the Duncan anticline much of the Badshot Formation is dolomite. In the region between Glacier Creek and the peninsula in Duncan Lake, the formation has been carefully studied by geologists of the Consolidated company (*see* Muraro, 1962), who recognized five members. The uppermost, as much as 200 feet thick, is a dark-grey to black very fine-grained siliceous dolomite. Commonly it has a strong lineation plunging northward parallel to the axes of minor folds; elsewhere it has an irregular black and white banding. The siliceous dolomite is underlain by about 50 feet of dark-grey and white flecked and banded dolomite, and the siliceous and underlying dolomite together are referred to as the upper dolomite. Beneath this dolomite is 5 to 20 feet of light-grey medium- to fine-grained crystalline limestone that commonly has a thin bed of grey micaceous phyllite at the base. Another thin member of dark-grey dolomite, called the lower dolomite, underlies the limestone, which in turn is underlain by a few feet of grey to white crystalline limestone at the base of the formation.

The section is summarized in the following table:—

		Ft.
Upper dolomite.	Dark-grey to black siliceous dolomite	50–200
	Dark-grey and grey-and-white flecked and banded dolomite	50
Lower dolomite.	Light-grey and grey medium-grained crystalline limestone with thin bed of grey phyllite at base	5–20
	Dark-grey flecked and light-grey dolomite	50–75
	Light-grey crystalline limestone	0–20

A somewhat different succession within the Badshot Formation is found on the slope north of Hamill Creek on the eastern limb of the Duncan anticline. In the lowest outcrops at 3,500 feet elevation, 150 to 200 feet of dark-grey siliceous dolomite is found near the base of the formation, and is overlain by 100 to 120 feet of buff to whitish fine-grained dolomite. Above the dolomite is 10 to 15 feet of micaceous grey limestone at the top of the formation. At an elevation of 4,000 feet, 100 feet of grey to white crystalline limestone forms the lowest member of the formation. It is overlain by 30 to 40 feet of dark-grey phyllite and argillite, which in turn is overlain by fine-grained dolomite at the top of the formation. The dolomite is partly dark grey to black and siliceous, and partly light grey and massive.

South of Hamill Creek the proportion of limestone in the Badshot Formation on the Duncan anticline increases. This is particularly evident on the western limb, where, south of Mount Willet, dolomite occurs only as lenses and several sections are entirely limestone. Siliceous dolomite is not generally present on the western limb of the Duncan anticline, and none is known south of Clint Creek. Locally a white quartz vein as much as 8 feet thick follows the top of the Badshot and is particularly continuous near the head of the south fork of Bulmer Creek.

Variations in the apparent lithologic sequence within the Badshot Formation on the Duncan anticline are due in part to structural complexities, but also are thought to result from vagaries of dolomitization and silicification.

West of the Duncan anticline the Badshot Formation consists of fine- to medium-grained grey and white crystalline limestone. The limestone weathers bluish grey and commonly contains dark-grey and white bands up to a few inches thick. Elsewhere fresh surfaces are white with dark-grey flecks, the remnants of bands destroyed by deformation. Dolomite is not found in the Badshot Formation west of the Duncan anticline except in a few localities such as on Lavina Ridge east of the St. Patrick syncline and on the shore of Kootenay Lake south of Argenta.

INDEX FORMATION

The Badshot Limestone is overlain by a thick succession of fine-grained dark-grey and green schists named the Index Formation, from Index Basin in the Ferguson area (*see* Fyles and Eastwood, 1962, p. 19). In the Duncan Lake area it consists of about 1,000 feet of dark-grey schist and minor micaceous limestone and quartzite overlain by what appears to be about the same thickness of green schist.

The grey schists (map unit 3a) and associated limestones and quartzites (map unit 3b) are referred to as the Lower Index, and the overlying green schists (map units 3c and 3d) and interlayered green and grey schists as the Upper Index. It has not been possible to map all rock units in the Index separately and to understand fully the stratigraphic relationships.

LOWER INDEX

The grey schists forming the Lower Index Formation include a variety of rock types which, with the exception of a few thin green layers, are grey, dark grey, or black. Carbonaceous and siliceous argillites, grey calcareous mica schists, dark-grey to black slates, dark blue-black limestones, and, in higher metamorphic grades, grey biotite, garnet, and staurolite mica schists are included in the Lower Index. They are mapped together as unit 3a on Figure 3. Although the unit contains a variety of rock types, little is known of the stratigraphic succession and none of the rock types has been mapped in detail.

The base of the Index Formation is sharply defined by the top of the Badshot limestone or dolomite. On the Duncan anticline and in the eastern belt a few tens of feet of highly carbonaceous argillite overlies the Badshot Formation. In general it is soft, but locally, as near Lavina Lookout, it is hard and siliceous. Elsewhere grey mica schist and, near the mouth of Hamill Creek and on the west slopes of Mount Willet, garnet staurolite mica schist form the base of the Index directly overlying the Badshot Formation.

The upper contact of the Lower Index Formation is poorly defined. In general fine-grained green schists overlie the grey schists, and near the contact the green and grey schists are commonly interlayered. In much of the map-area the uppermost few hundred feet of the grey schist is calcareous. Layers and lenses of dark-grey fine-grained limestone an inch or so thick occur within the grey schist. The lenses are crumpled and streaked-out beds that once formed parts of complex folds, and they produce a strong lineation. Similar rocks are found elsewhere in the Lower Index Formation, but they are characteristic of its uppermost part.

On Howser Ridge west of Jubilee Point the upper limy part of the Lower Index grades into grey limestone, micaceous limestone, and greyish-brown quartzite shown as unit 3b on Figure 3. The limestone is grey to creamy white and fine grained. Some 10- to 50-foot sections are clean limestone, but most commonly the limestone contains wisps and thin layers of grey mica schist. The quartzite is brown, whitish brown, or greyish brown with white or opalescent rounded quartz grains up to about 2 millimetres across and locally with visible white feldspar crystals. It contains grey micaceous wisps or partings and has an irregular fracture and in general a poor foliation.

The limestone and quartzite outcrop along the upper western slope of Howser Ridge in a belt a mile and a half wide that crosses Lake Creek and forms the upland area of Johnson Mountain just beyond the map-area (*see* Mathews, 1953). Structurally simple sections of these rocks are found at very few places in this belt, and the rocks are not known elsewhere in the map-area. Along the northeastern side of the belt the quartzite appears to overlie grey schist and to underlie the limestone. The limestone in turn is overlain by green schist. These relationships are well exposed on the upper east slope of Howser Ridge due west of Jubilee Point and on the north side of Lake Creek. In the interior of the belt, complexity of the structure obscures the stratigraphic relationships, and along the southwestern margin the lithology of the quartzites and green schists is somewhat different than it is to the northeast. The quartzites near the southwestern margin of the belt are greenish-white to brownish micaceous rocks with visible grey or white quartz and locally feldspar grains. They grade southeastward into fine-grained grey and brown and locally greenish micaceous quartzites and dark-grey argillites which outcrop on lower Howser Ridge from the Duncan River to more than a mile northwest of Howser. Scattered occurrences of limestone are found with the quartzites. Green schists and phyllites to the southwest are largely volcanic rocks of the Upper Index.

The limestones and quartzites in the upper part of the Lower Index (map unit 3b) are found only on Howser Ridge and the slopes of Lake Creek. They continue southeast along Howser Ridge with some lithologic variation and are not found to the west on Lardeau Ridge or west of Meadow Creek and Lardeau Bluff. The limestones and quartzites are regarded as sedimentary facies at the top of the Lower Index which grade into calcareous grey mica schists occurring in most of the area. It is significant that limestones and coarse quartzites like those on Howser Ridge are found locally in the Index Formation in the Ferguson area (*see* Fyles and Eastwood, 1962, p. 20).

UPPER INDEX

Rocks of the Lower Index Formation are overlain by various kinds of fine-grained green schists (map units 3c and 3d). They are exposed in the Howser syncline, in a narrow belt west of the Duncan anticline, in the St. Patrick syncline, and in the southwestern belt.

The two main rock types found in the Upper Index, and identified mainly from the study of thin-sections, are quartz-muscovite-chlorite schists and feldspar-chlorite schists. The quartz-muscovite-chlorite schists (map unit 3c) are found largely in the Howser syncline but occur also on the eastern slope of Howser Ridge west of the Duncan mine and as thin layers elsewhere in the area. The feldspar-chlorite schists (map unit 3d) are found mainly in the St. Patrick syncline and west of it.

The quartz-muscovite-chlorite schists are fine-grained light- or dark-green rocks with a slightly rusty weathered surface. They have a more or less well-developed schistosity. Banding or bedding is rarely seen, and no distinctly contrasting lithologies are recognized within the map unit. In general these schists are relatively hard and form bold outcrops, but on the western limb of the Howser syncline they are strongly schistose and form subdued outcrops. Thin-sections show that quartz-muscovite and chlorite are present in about equal amounts, and that tourmaline, apatite, and locally epidote are minor constituents. Quartz occurs as a mosaic of anhedral grains less than 0.2 millimetre across, and rarely these grains form rounded clusters, the remnants of original detrital grains. South of the Lower Arm, scattered porphyroblasts of brown garnet 2 to 4 millimetres across are present. Small octahedra of magnetite are found locally.

The feldspar-chlorite schists include a variety of rock types which are mainly of volcanic origin. In general they are very fine-grained dull green, olive green, or dark green, more or less schistose rocks without banding or other primary structures. Some are poorly foliated, fine to medium grained, and resemble metamorphosed diorites. In general the feldspar-chlorite schists are calcareous, and locally lenses of sugary white limestone up to a few inches thick are intercalated with them. Also, layers of fine-grained green or grey quartzite, resembling chert, are present locally. Rarely, rounded or elongate amygdules of epidote, chlorite, and carbonate or vague amygdaloidal fragments can be distinguished.

Thin-sections show that many of the feldspar-chlorite schists contain rounded or angular detrital crystals of andesine and, less commonly, rounded quartz grains. These rocks are greywackes or tuffaceous sediments. They contain mainly chlorite and plagioclase with or without quartz, muscovite, epidote, carbonate, and accessory tourmaline. Amphibole is not generally present in rocks which contain clearly detrital grains. Other feldspar-chlorite schists contain feathery hornblende or light-green amphibole together with chlorite, epidote, carbonate, and, in some specimens, green biotite. Many of these rocks containing amphiboles are probably flows or related intrusions.

The stratigraphy of the Upper Index and the immediately underlying upper part of the Lower Index probably changes from place to place. Marker horizons, which might suggest the nature of the changes, are not present, though the upper contact of the grey mica schist has been mapped as a horizon. In the Howser syncline the relationships of the Upper and Lower Index appear simple—the lower grey schist, which is calcareous near the top, is overlain by a uniform quartz-muscovite-chlorite schist. To the southwest in the St. Patrick syncline, on both sides of the Lardeau River, and in the southwestern part of the area, the Lower Index grey schist is overlain by feldspar-chlorite schist. On the western slope of Howser Ridge and across the valley of Lake Creek where the upper part of the Lower Index is a limestone-quartzite succession, green schists which apparently overlie the limestone are mainly of the feldspar-chlorite type. Thus in general the feldspathic rocks are in the west and northwest, and it is concluded that the Upper Index becomes more volcanic in character toward the northwest.

Complex repetitive folding, which largely obscures evidence of stratigraphic relationships, has produced in some places complicated interlayering of all the rock types in the Index. Green schists in layers a few feet to a few hundred feet thick are interlayered with limestones, quartzites, and grey schists on the upper western slopes of Howser Ridge and to the west across the valley of Lake Creek. Grey schists and green quartz-muscovite-chlorite schists intricately intertongue on Howser Ridge about 2 miles north of Howser, and careful mapping shows that the green tongues in the grey are isoclinal synclines and the grey tongues are isoclinal anticlines, all plunging to the north. On Lardeau Ridge and west of Meadow Creek and the Lardeau Bluff, green quartz-chlorite-muscovite schists, green feldspar-chlorite schists, and grey mica schists are complexly interlayered and are shown together as unit 3 on Figure 3. The layers are a few tens to a few hundred feet thick. It is thought that the interlayering results at least in part from repetitive isoclinal folding. There is little direct field evidence for this, but this conclusion is based on the fact that where the stratigraphy is known, thick, complexly interlayered sequences are produced by repetitive folding. Although repetitive folding probably accounts for much of the interlayering, some of the interlayers of green and grey schist may be of sedimentary or volcanic origin. Some of the grey schist probably belongs to the Triune Formation (map unit 4), which overlies the Index.

TRIUNE, AJAX, AND SHARON CREEK FORMATIONS

The Index Formation is overlain by dark-grey argillite and argillaceous quartzite of the Triune Formation. Grey blocky quartzite, the Ajax Quartzite, overlies the Triune Formation, and dark-grey to black argillite of the Sharon Creek Formation overlies the Ajax. These three formations were named from localities in the Ferguson area (*see* Fyles and Eastwood, 1962, p. 22), where they were mapped separately. In the Duncan Lake area they are mapped together because of the scale of mapping and the lenticularity of the formations. The formations are well exposed only on Howser Ridge in the trough of the Howser syncline, and they continue to the northwest beyond the map-area. They are poorly exposed on the slopes west of Meadow Creek and the Lardeau Bluff and in a narrow band on the north side of Lake Creek 1½ miles from its mouth.

The Triune Formation exposed on Gallop Creek and on the slopes southeast of the creek consists of interbedded grey quartzite and dark-grey argillite in beds less than 2 inches thick. On the northeastern limb of the Howser syncline the Triune Formation is dark-grey argillite locally containing very fine-grained quartzitic beds resembling dark-grey chert. The base of the Triune is in sharp contact with the underlying green schists of the Upper Index. The top is difficult to define because the Ajax is lenticular. The total thickness appears to be about 500 feet. On the southwestern limb of the Howser syncline the Triune Formation is generally very thin and poorly exposed. Just below the crest of Howser Ridge on the southeast side, it is about 200 feet thick and consists of dark-grey slate and argillite with narrow interbeds of quartzite.

The Ajax Formation, which overlies the Triune, is a fine-grained massive grey quartzite. In general, bedding is not visible, but locally thin calcareous beds and lenses are present, which weather to a buff-coloured sand. In these beds, and in rounded concretionary masses commonly associated with them, calcite forms a cement for rounded quartz grains less than 1 millimetre in diameter. Dark-grey argillite and slate are found at a few places in the Ajax Formation, and beds of conglomerate containing angular fragments of dark-grey argillite in a sandy or limy matrix are seen locally. The Ajax Quartzite characteristically contains many irregular white quartz veins up to several feet thick.

The Ajax Quartzite is overlain by the Sharon Creek Formation of dark-grey to black argillite. It typically forms rusty-weathering blocky beds which are more or less well cleaved. At one place on the southwest side of Howser Ridge near the base of the formation, beds of dark blue-grey limestone a few inches thick alternate with beds of argillite. In the trough of the Howser syncline exposed in Gallop Creek at an elevation of about 4,000 feet, the Sharon Creek Formation is highly crumpled black slate.

The Ajax Quartzite found on the northwest side of Lake Creek about 1½ miles from its mouth forms a layer a few tens of feet thick which has been traced from near the creek to an elevation of 5,300 feet on the ridge north of the creek. It is in an area of intense shearing. Dark-grey and black slates and argillites associated with the quartzite are correlated with the Triune and (or) Sharon Creek Formations but are not differentiated in this area. Green feldspar-chlorite schists of the Upper Index are on both sides of the slate, argillite, and quartzite. All these rocks continue northwest beyond the map-area. The Ajax is not found southeast of Lake Creek, and black slates continue no more than a mile to the southeast. The black slates southeast of Lake Creek are difficult to distinguish from similar rocks in the Index, but the presence of Ajax Quartzite north of Lake Creek has led to their correlation with the Triune or Sharon Creek. These rocks are in an area of complex structure. A more complete knowledge of structure and stratigraphy must await further mapping to the northwest.

Rocks correlated with the Triune, Ajax, and Sharon Creek Formations are found at a number of places in the southwest belt, particularly west of Meadow Creek and the Lardeau Bluff. They are immediately east of outcrops of the Jowett Formation of schistose volcanic rock and are exposed best in the canyons of John and Cooper Creeks, but they are also seen on the logging-roads south of John Creek and on the gentle slopes west of the Lardeau Bluff. The formations are dominantly dark-grey to black slate and argillite, locally containing beds of grey and light-grey quartzite. The quartzites in general are finer grained and darker in colour than the Ajax on Howser Ridge. Olive-green and greyish-brown tuffaceous sediments occur with some of the argillites.

In Cooper Creek canyon, dark-grey to black argillite containing several beds of quartzite is about 100 feet thick. Volcanic rocks of the Jowett Formation lie to the west, and tuffaceous green and grey schists of the Upper Index lie to the east. On the south slope of John Creek, highly contorted black slates and argillites at least 100 feet thick lie east of the Jowett and west of the Index. No Ajax Quartzite has been found at this locality. Between Cooper and Davis Creeks 20 to 30 feet of Ajax Quartzite is exposed in a 100- to 150-foot layer of black argillite containing greenish and brownish tuffaceous lenses. In all these localities the westerly contact of the Sharon Creek with the Jowett is well defined, but the easterly contact is poorly marked; the grey and green schists and argillites grade into rocks of the Index Formation. Because of this the Sharon Creek, Ajax, and Triune are shown locally on Figure 4 but are not shown on Figure 3, where they are included in map unit 3. Correlation of these rocks with the Triune, Ajax, and Sharon Creek Formations from place to place in the area is based on lithology and on the stratigraphic relation to the Jowett and Index Formations, both of which are correlated with certainty. Studies in the Ferguson area have shown that stratigraphic changes, especially in the thickness of the Ajax and lithology of the Triune, are to be expected. In the Duncan Lake area the Ajax appears to become finer grained to the southwest, and all three formations tend to thin and to intertongue with tuffaceous sediments. The Ajax probably grades into dark-grey argillite.

JOWETT FORMATION

The Jowett Volcanic Formation overlies the Sharon Creek. It was named in the Ferguson area (*see* Fyles and Eastwood, 1962, p. 24) from exposures of mafic volcanic rocks on Mount Jowett. In the Duncan Lake area the formation outcrops along the southwestern side of the map-area in a belt 500 to 2,000 feet wide which widens toward the northwest and continues beyond the map-area both to the north and to the south. The Jowett is also found in the Howser syncline on Howser Ridge, but in that locality it is too thin to be shown on Figure 3.

In the Howser syncline the Jowett consists of 15 to 20 feet of olive-green fine-grained calcareous chlorite schist lying between black argillite of the Sharon Creek Formation and green quartzose schists and grits of the overlying Broadview Formation. It is well exposed on the southwestern limb of the syncline on Howser Ridge and alpine slopes to the north. In thin-section the schists contain very fine-grained chlorite, epidote, plagioclase, and minor quartz and narrow lenses of calcite.

In the southwestern part of the map-area the Jowett Formation is composed of a fine-grained green schist grading into fairly blocky greenstone. In general the rocks have a poor schistosity that is pronounced near the margins of the formation and is virtually absent in the centre of the formation north of John Creek, where it is abnormally thick. The rocks contain no primary structures, but thin light-green bands and locally lenses of limestone a fraction of an inch thick are probably remnants of bedding. Rounded or streaked out, generally rusty-weathering lenses of calcite less than an inch long resemble deformed amygdules, and larger lenses of white limestone may be interpillow material. Clean exposures of greenstone or rocks with a poor schistosity locally show pillow structures. Pillow structures exposed on the north side of Cooper Canyon and on the ridge south of Mat Creek are about a foot across and are irregular, elongate, and outlined by a dark-green band an inch or so thick. In John Creek and upper Meadow Creek the Jowett Formation is mainly massive greenstone. The eastern margin is not readily defined because the greenstone is complexly interlayered with dark-grey argillite resembling the Sharon Creek Formation. Some of the interlayers of greenstone are probably sill-like intrusions. The eastern contact of the Jowett in John and upper Meadow Creeks as shown on Figure 3 is probably not a stratigraphic horizon but is a line west of which there are insignificant amounts of dark-grey argillite in the greenstone.

The principal constituents of rocks of the Jowett Formation identified under the microscope are plagioclase (andesine), chlorite, and epidote with or without quartz, amphibole, biotite, and calcite. Many of the rocks contain crystals of magnetite, some of which are as much as 5 millimetres across. Quartz-bearing green schists generally show sedimentary characteristics in thin-section. They contain rounded and angular detrital fragments of quartz and plagioclase in a chloritic matrix and are regarded as tuffaceous sediments or greywackes. Rocks with pillow structures or amygdules generally contain hornblende or a feathery light-green amphibole. Both in the field and in thin-section these rocks closely resemble the feldspar-chlorite schists of the Upper Index. Because of this, a broad area of outcrop of fine-grained feldspar-chlorite schists northeast of Goldhill and in the canyon of Lake Creek mapped as Index Formation may in fact be part of the Jowett.

The apparent thickness of the Jowett Formation increases from a few hundred feet in the southwestern corner of the map-area to several thousand feet north of John Creek. This increase in the apparent thickness is in part a result of the structure, but mainly it reflects an increase in the original thickness of the formation.

BROADVIEW FORMATION

Green and locally grey micaceous quartzites, greywackes, grits, and fine-grained mica schists of the Broadview Formation overlie the Jowett. They are exposed on Howser Ridge in the trough of the Howser syncline and along the southwestern edge of the map-area. Studies in the Ferguson area and west of the Duncan Lake area in the vicinity of Meadow Mountain have shown that the Broadview is a very thick formation of dominantly grey and green quartzite and grit with interbedded schists, and minor limy and volcanic rocks. Although it is composed of a varied succession, very few members are distinctive enough to be traced and mapped separately, and the formation has not been subdivided. Only the lowermost part of the Broadview is exposed in the Duncan Lake area.

North of Cooper Creek and on the ridge between Cooper and Davis Creeks, the lowest member of the Broadview is a fine-grained grey mica schist 40 to 50 feet thick. It is locally calcareous and is overlain by an unknown but relatively great thickness of greenish micaceous quartzite. The lower 500 or so feet of this quartzite contains a number of layers of fine-grained chlorite schist, above which are greyish layers and beds of coarse greenish or light-grey grits and fine pebble conglomerate. South of Cooper Creek the grit and fine-grained conglomerate form prominent ridges of continuous outcrop. Farther west and higher in the sequence, the quartzites are dominantly grey and contain layers and lenses of dark-grey phyllite and mica schist. Coarse- and fine-grained greywackes with visible feldspar fragments are found locally in the quartzitic rocks both north and south of Cooper Creek.

In the Howser syncline the Broadview is dominantly green fine-grained mica schist and micaceous quartzite. A few beds with visible quartz grains are present, and no coarse grit or greywacke is known.

Bedding in rocks of the Broadview is commonly difficult to see because it is obscured by other structures. Locally bedding is pronounced and commonly shows complex folds and intersecting cleavages (*see* Plate XII). Primary structures such as graded bedding or cross-beds by which stratigraphic tops might be determined have not been found.

TABLE SHOWING LITHOLOGICAL CORRELATIONS IN PARTS OF THE UPPER HAMILL AND LOWER LARDEAU GROUPS

FERGUSON AREA			DUNCAN LAKE AREA							SALMO AREA					
Name	Approx. Thickness (Ft.)	Lithology	Name	Approx. Thickness (Ft.)	Meadow Creek Anticline	Approx. Thickness (Ft.)	Duncan Anticline	Approx. Thickness (Ft.)	Eastern Belt		Name	Approx. Thickness (Ft.)	Mine Belt	Approx. Thickness (Ft.)	Sheep Creek Anticline (South Salmo River)
Index.	500(?)	Green and grey phyllite and dark-grey argillite.	Lower Index.	1,000	Dark-grey mica schist.	1,000	Grey mica schist and dark-grey argillite.	1,000	Grey mica schist, grey phyllite, and dark-grey argillite.		Emerald Member.	200–500	Black phyllite and grey calcareous argillite.	(?)	Brown-weathering grey siliceous argillite.
Badshot.	700–1,000	Fine-grained grey limestone.	Badshot.	0–200	Grey and white crystalline limestone.	100–300	Grey and white crystalline limestone and dolomite; siliceous near top.	0–350	Limestone siliceous near top.		Reeves Member.	200–400	Grey and white crystalline limestone; local dolomite.	450	Grey fine-grained limestone.
Mohican.	1,000–1,500	Dark-grey and green phyllite; locally dark-grey limestone.	Mohican.	0–75	Grey and green mica schist with thin calcareous interbeds.	100–300	Interbedded mica schist and limestone or dolomite; beds a few feet thick.	300–500	Grey and green mica schist.	Laib.	Truman Member.	50–100	Grey-brown mica schist, phyllite, and argillite.	350	Grey-green and brown phyllite with calcareous lenses.
								0–200	White to grey limestone.						
								100–300	Limestone and mica schist.						
	0–50	Grey to buff-weathering white limestone.				0–10	White buff-weathering limestone.	0–25	Buff-weathering white limestone.			0–20	Buff-weathering white argillaceous limestone.		Lenses of impure white limestone.

Marsh-Adams.	50–100	Brown argillaceous quartzite and grey locally calcareous quartzite and grit.	Marsh-Adams.	0–40	Grey blocky to platy quartzite.	0–20	Blocky to platy grey quartzite; minor lenses calcareous grit.	10–30	Grey to pinkish-brown quartzite; visible quartz grains; lenses with calcareous cement.		Reno.	40–50	Blocky grey quartzite; lenses of calcareous quartzite and micaceous quartzite.	60	Blocky grey quartzite; coarse quartz grains in calcareous cement in upper part.
		Thin-bedded grey to brownish micaceous quartzite.		200–400 (?)	Grey and brown micaceous quartzite and mica schist.	250–350	Brown and grey micaceous quartzite and mica schist.	400	Grey-brown platy micaceous quartzite.			500	Grey-brown to grey micaceous quartzite.	500–600	Grey micaceous quartzite and dark grey-black phyllite.
				100	Platy white quartzite.	100–200	Platy white quartzite	200	Platy white quartzite.	Quartzite Range.	Upper Nevada.	50–150	Platy white quartzite.	250	White quartzite.
	(?)	Interbedded white and grey or brown micaceous quartzite.			Not exposed.	Few hundred	Interbedded brown micaceous and white quartzite; minor green mica schists and brown-weathering buff limestone.	Few hundred	Grey locally green micaceous quartzite; few calcareous lenses near base.		Lower Nevada.	250(?)	Brown micaceous quartzite with greyish-white interbeds; local greenish phyllite and white micaceous limestone.	400	Thin-bedded greyish-white quartzite and grey-brown micaceous quartzite; some greenish-grey phyllite.
Mount Gainer.		Blocky white quartzite.		(?)	Blocky white quartzite.	(?)	Blocky white quartzite.	500(?)	Blocky white quartzite.		Nugget Member.		Massive white quartzite.	100–400	Massive white quartzite.

CORRELATIONS BEYOND THE MAP-AREA

Detailed geological work in the Ferguson, Duncan Lake, and Salmo areas has been aimed mainly at determining the structure, but has also yielded stratigraphic data. Although the present knowledge of the structure is sufficient to provide a basis for regional stratigraphic studies, so far such studies have not been made. The following paragraphs describe briefly some features and some existing problems of the stratigraphy of the Palæozoic rocks in the Kootenay arc as a whole.

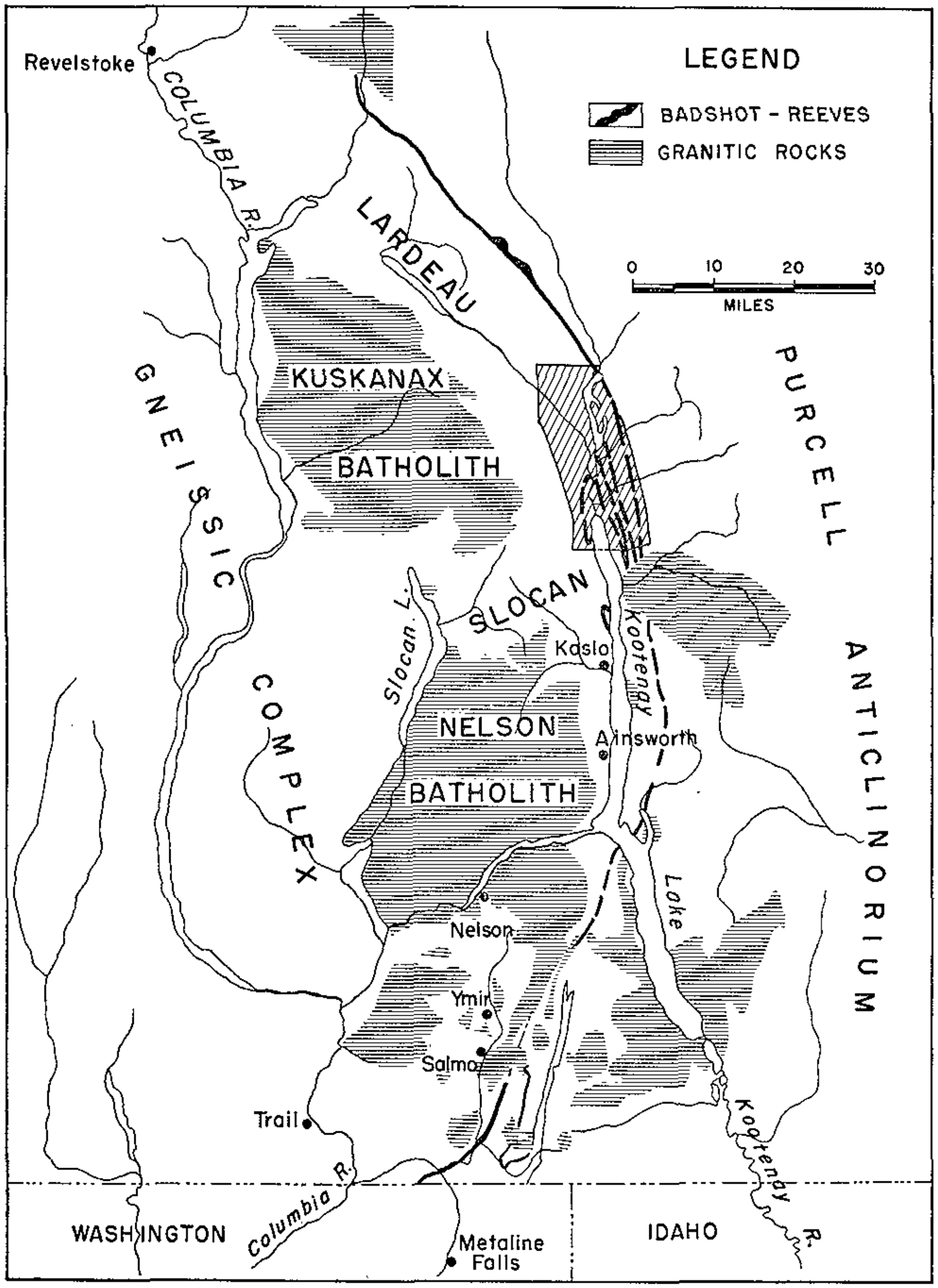

Figure 5. Map of the Kootenay arc showing the trace of the Badshot-Reeves Limestone and the principal granitic masses. Duncan Lake area in oblique shading.

Correlations within Palæozoic rocks of the Kootenay arc are based largely on lithologic characteristics of individual formations and members and on rock sequences. For many years the Badshot limestone has been regarded as a marker bed of regional significance, although it has not been completely mapped in detail. Regional maps (Little, 1960; Rice, 1941; Walker and Bancroft, 1929) have linked the type locality on Badshot Mountain in the Ferguson area with a limestone in the Salmo area 150 miles to the south known as the Reeves Limestone (*see* Fig. 5). Archæocyathids have been found in or near the Reeves Limestone in the Salmo area (*see* Little, 1960) and in northwestern Washington (*see* Park and Cannon, 1943; Mills, 1962) and form the basis for regarding the Reeves and Badshot as Lower Cambrian. Recently (Wheeler, 1962, p. 6) archæocyathids have been discovered in the Badshot of the Rogers Pass area some 50 miles northwest of the type locality. Although fossils are known in other Palæozoic rocks, particularly in the southern part of the arc, they are scarce, and it is not possible to make correlations based on fossil evidence or to compare lithologies during specific intervals of geologic time.

Studies of the Badshot-Reeves Limestone and nearby formations have shown the lithologies to be extremely uniform over an area 150 miles from north to south parallel to the structural trends and several tens of miles from east to west. Six columnar sections are given in the table on page 32. All six sequences are readily correlated, and each contains several distinctive markers. One marker that is most distinctive is a white or honey coloured, somewhat micaceous limestone at the base of the Mohican Formation and of the Truman Member. It is thin and lenticular but is present in most sections of these rock units. It lies above and grades into a grey calcareous quartzite at the top of the Marsh-Adams and Reno Formations. This quartzite, which is no more than a few tens of feet thick, is also a distinctive marker, but it changes systematically from east to west. In the east it contains coarse quartz grains and shows well-marked cross-bedding, while in the west it is fine grained and not cross-bedded. This characteristic is noted in both the Duncan Lake and Salmo areas, and clearly indicates a shoreline and sedimentary source area to the east. A shoreline in the same direction is indicated by similar sedimentary facies changes in many of the quartzites in the Upper Hamill.

Correlations within the Badshot and Mohican Formations are less certain than they appear in the table. In the Duncan Lake area the formations cannot be traced continuously from the eastern belt through the Duncan anticline to the Meadow Creek anticline. Contrasting facies of the Mohican Formation in these localities have been described (*see* p. 22), and in the eastern belt the Badshot is known to be lenticular. On the Comb Mountain antiform (*see* p. 47), the closest link between the eastern belt and the Duncan anticline, the Badshot Limestone is very thin or absent and a thick limestone near the centre of the Mohican is prominent. It is possible that the Badshot lenses out entirely toward the west, and that the limestone called the Badshot on the Meadow Creek anticline is in fact the prominent limestone in the Mohican. The Badshot Limestone and the immediately underlying grey schists of the eastern belt may grade westward into grey schists of the Lower Index on the Meadow Creek anticline. At present there is no way of proving or disproving this possibility.

A somewhat similar possibility exists in the Salmo area between the Sheep Creek anticline and the eastern limb of the Laib Creek syncline (*see* Little, 1960, p. 105), where the Reno and Truman are repeated several miles east of the anticline. The section in the Laib Creek syncline has not been studied in detail (though it is now readily accessible from the new Salmo–Creston highway), but it appears that the prominent limestone in this section is immediately above the Reno Quartzite and that the Reeves Limestone member is thin and inconspicuous. Incidentally, it is the prominent limestone on the eastern limb of the Laib Creek syncline that has yielded essentially all the archæocyathids found in the Salmo area.

The sections summarized in the table on page 33 are the best known and most strikingly similar sections in the Kootenay arc. Rocks in the upper part of the Lardeau Group (Upper Index Formation and younger) contrast with formations found in the Salmo area and northeastern Washington, and the significance of these contrasting facies is one of the major stratigraphic and structural problems of the arc. The Metaline Limestone of northeastern Washington, called the Nelway Formation in the Salmo area (*see* Little, 1960, p. 35) is not found far north of Ymir. It contains Middle Cambrian fossils and is overlain by black slates and argillites of the Active Formation containing Ordovician graptolites. The Active Formation also is not recognized far north of Ymir. Lithologies in the Duncan Lake and Ferguson area continue to the north (*see* Wheeler, 1963, p. 7), and a striking similarity between the Ferguson section and that in the Cariboo River area has been described by Sutherland Brown (1963, p. 42). The Broadview Formation is not known south of Milford Peak near Kaslo, and the Ajax and associated black argillite has not been recognized south of the town of Lardeau. The Broadview Formation underlies with probable unconformity rocks of the Milford Group containing Mississippian fossils (*see* Fyles and Eastwood, 1962, p. 32), and the Ajax Quartzite may be equivalent to the Yanks Peak Quartzite of the Cariboo Mountains, which contains probably Ordovician fossils. These relationships suggest that the sedimentary conditions that existed over wide areas in the northern part of the Kootenay arc and beyond it in early and mid Palæozoic time differed markedly from those in the southern part of the arc. Whether these conditions produced sedimentary facies changes in a north-south direction parallel to the structural trends or whether contrasting eastern and western facies have been brought together by tectonic movements is a problem for further study.

FELSITE

Sills of felsite are common in the southwestern part of the map-area and along the eastern side of the Duncan River and Kootenay Lake. Their distribution is shown on Figure 6. Characteristically they are blocky rocks which are white and locally rusty on weathered surfaces and light grey to buff on fresh surfaces (*see* Plate IX). Strictly defined they are feldspar porphyries and fine-grained aplite. They range from a few inches to a few hundred feet thick and most commonly are 1 to 20 feet thick. The largest mass in the map-area forms a prominent hill on the north side of Cooper Creek and is a curved sill-like sheet of aplite 200 to 300 feet thick that tapers to north and south and down dip to the west. The felsites form continuous sheets or clusters of sheets parallel to the most prominent foliation of the enclosing rocks. Some felsites end abruptly or are broken into a series of lenses to form a pronounced boudinage structure. The long axes of the boudins plunge either down the dip of the sills or plunge parallel to the prominent lineation in the enclosing rocks, a direction which in general is nearly parallel to the strike of the sills. Some of the sills branch and transgress the foliation at small angles.

The majority of the sills are porphyritic with phenocrysts of feldspar and locally of quartz 1 to 3 millimetres across in an aphanitic matrix. The largest are fine-grained aplites, and all have narrow, poorly defined aphanitic margins. Minor amounts of the mafic constituents commonly form elongate clusters, giving the rocks a poor lineation which is parallel to the prominent lineation in the enclosing rocks. The sills are not foliated, and the lineation is poorly developed.

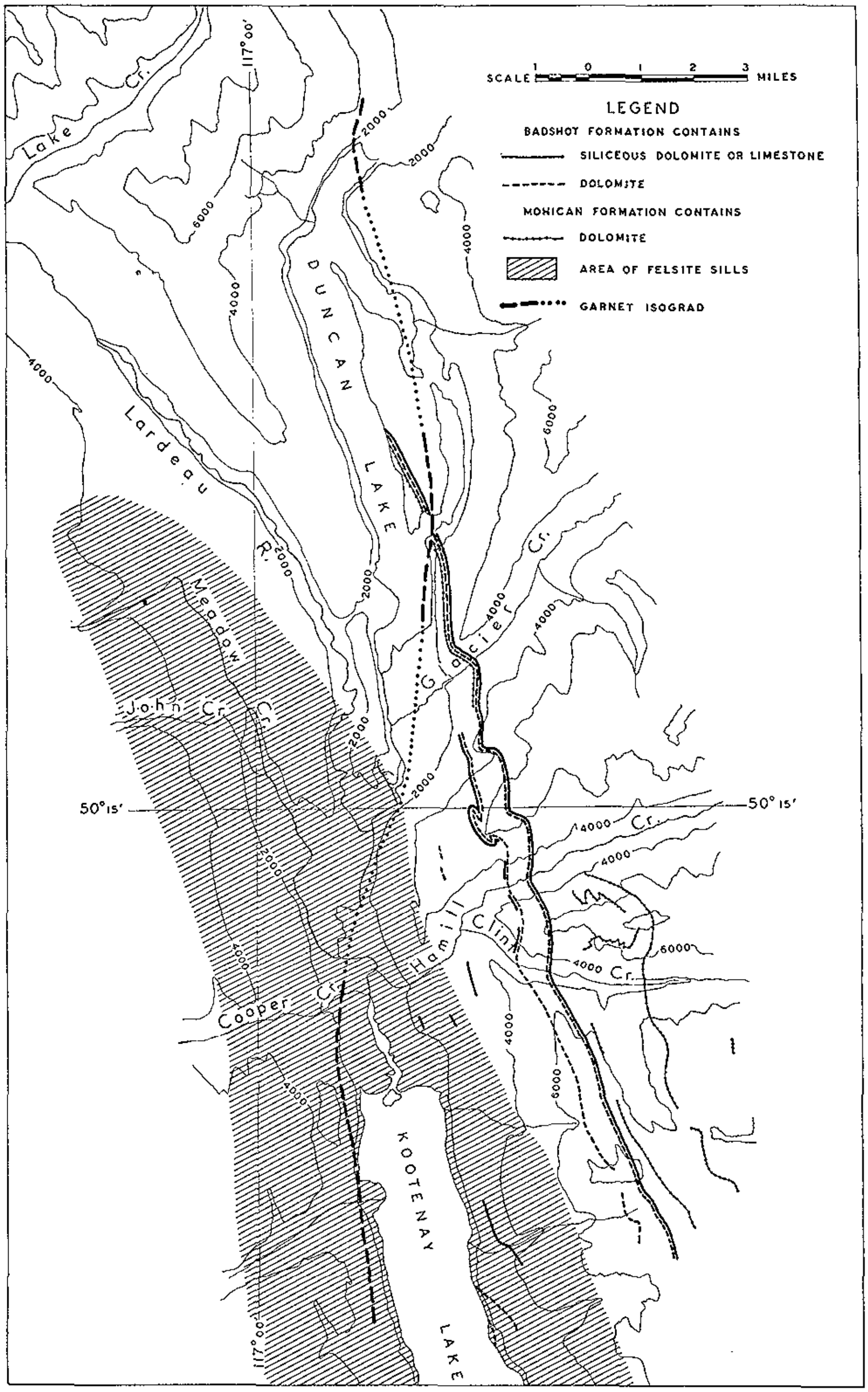

Figure 6. Map showing the garnet isograd and the distribution of felsites, dolomite, and siliceous dolomite in the Duncan Lake area.

Most specimens of felsite contain 40 to 60 per cent phenocrysts, which, under the microscope, are identified as microcline and smaller amounts of plagioclase. Only one thin-section studied contained quartz phenocrysts. The microcline is microperthitic, and the plagioclase is either oligoclase or andesine. The matrix is a mosaic of quartz and feldspar in grains generally about a tenth of a millimetre across. Muscovite and biotite usually make up less than 5 per cent of the rock but may amount to as much as 10 per cent. They have a random orientation, except in one section where they are oriented and bent around the phenocrysts. Sphene, apatite, chlorite, epidote, carbonate, and pyrite are minor constituents.

MAFIC DYKES AND SILLS

Very few mafic dykes and sills are found in the Duncan Lake area. They are of two general types—deformed amphibolites and essentially undeformed dark-grey rocks classed as lamprophyres.

The *amphibolites* form more or less well-foliated masses, the largest of which are exposed on both sides of Clint Creek and along the valley of the south fork of Clint Creek in rocks of the Marsh-Adams Formation (*see* Figure 3, rock unit A). Smaller masses of amphibolite are found in the Mohican Formation on the Duncan anticline and also locally west of the Duncan anticline on the north slope of Lavina Ridge. The layers of amphibolite in Clint Creek are a few hundred feet thick, and in single exposures appear concordant with the enclosing quartzite. Careful mapping, however, shows that they gradually transgress the formations and appear at various stratigraphic levels within the Marsh-Adams Formation. Along Clint Creek itself they are fine- to medium-grained dark-green or green-and-white mottled rocks with a very poor foliation. Thin-sections show they are composed mainly of hornblende and feldspar (oligoclase or andesine) with minor quartz, epidote, chlorite, apatite, and magnetite. To the south they become more coarsely crystalline, and on the pass at the head of the south fork of Clint Creek they contain crystals of hornblende, biotite, and epidote as much as an inch long. The smaller masses of amphibolite on the Duncan anticline are lithologically very similar to the finer-grained parts of the amphibolites near Clint Creek, and they all closely resemble parts of the Index and Jowett Formations. The amphibolites appear to have been deformed together with the enclosing rocks, and it is possible that they are intrusive facies of the volcanic parts of the Index and Jowett Formations.

Lamprophyre dykes and sills have been found at less than half a dozen localities in the Duncan Lake area, but are of interest because they form part of a suite of late igneous rocks found widely in the Kootenay arc to the south. In the Duncan Lake area they are dark greenish-grey rocks forming dykes or sills a few feet thick. They are blocky with a porphyritic texture, narrow chilled margins, and commonly a compositional banding parallel to the contacts. Many of the phenocrysts are rounded and resemble amygdules, but thin-sections reveal that they are mainly talc or serpentine which appears to have replaced rounded olivine crystals. The phenocrysts, which are as much as 5 millimetres across, are set in an altered aphanitic groundmass containing mainly biotite. Chlorite, calcite, and magnetite are minor constitutents seen in thin-section. Though altered, the rocks are not foliated. They closely resemble biotite-olivine lamprophyres in the Salmo area (*see* Fyles and Hewlett, 1959, p. 45).

REGIONAL METAMORPHISM

Within the Duncan Lake area the grade of regional metamorphism increases from a low grade characteristic of the northwest-trending part of the Kootenay arc northwest of Duncan Lake to garnet and higher grades characteristic of rocks along Kootenay Lake. This increase in metamorphic grade is marked by changes in the mineralogical composition of the rocks. Metamorphic changes in individual formations are described in the foregoing parts of this chapter; a general summary of these changes is given here. In the present work the study of metamorphism has largely been incidental to the study of the structure and the mineral deposits.

In the field, considerable attention has been paid to the first appearance of the classic metamorphic index minerals which, in the micaceous rocks of the Duncan Lake area, include chlorite, biotite, garnet, and staurolite. Only the garnet isograd has been placed with certainty (*see* Fig. 6), and it has been drawn by joining points at which garnets first appear in the Mohican Formation. The garnet iograd is a northerly trending line, west of which garnets have not been found in any of the formations and east of which garnets may be present in any formation. The place at which garnets first appear varies from one formation to another because of differences in the original composition. In quartz-mica schists of the Upper Index and Marsh-Adams Formations garnets begin to show up quite close to the garnet isograd, but in grey schists of the Lower Index garnets are not found for considerable distances within the garnet zone. In the Howser syncline, for example, much of the green chlorite-quartz-mica schist of the Upper Index contains small brown garnets everywhere south of the Lower Arm of Duncan Lake, but the grey carbonaceous schists of the Lower Index adjacent to them are free of garnet as far as the slope north of Hamill Creek. South of this point the grey schists contain abundant brown garnets up to a centimetre across.

Within the garnet zone, chloritoid, mainly as porphyroblasts up to 3 millimetres across, is common in the Mohican Formation and is found locally in the least carbonaceous parts of the Lower Index, especially in the eastern belt. Brown biotite is widely scattered and is particularly conspicuous as porphyroblasts in the Lower Index south of Hamill Creek and in calcareous parts of the Mohican Formation in the eastern belt. Epidote is found in a few thin-sections. Plagioclase identified as oligoclase occurs as inconspicuous crystals in some thin-sections of the Mohican Formation. It is more abundant south of Hamill Creek than to the north.

The metamorphic grade clearly increases to the south along the formational strike, as indicated by the appearance of minerals such as staurolite and amphibole and by the coarser grain and higher degree of crystallinity of the minerals. Staurolite found in thin-section is present near the base of the Index Formation on the north side of Hamill Creek just east of the Duncan River. In an equivalent layer south of Hamill Creek, porphyroblasts of staurolite can be seen in the field. Staurolite is conspicuous in this layer, which is a few tens of feet thick and has been traced from near the mouth of Clint Creek to Bulmer Creek, and though present locally is inconspicuous in other parts of the Index. Staurolite has also been found in thin-sections of the Mohican Formation on the eastern limb of the Duncan anticline south of Clint Creek, but the general distribution of staurolite is not known well enough to define a staurolite isograd. Pale bluish-green amphibole is present in parts of the Mohican south of Hamill Creek and is not found to the north. All the mica schists are generally coarser grained south of Hamill Creek than they are north of Glacier Creek. Vague outlines of sedimentary grains can be seen in thin-sections of quartzitic schists north of Hamill Creek, but none of these grains is visible in rocks to the south. The metamorphic minerals in thin-section are more clearly defined in the south than they are in the north.

West of the garnet isograd, minerals characteristic of a low grade of regional metamorphism are found. In the mica schists, muscovite and chlorite are the principal metamorphic minerals. Biotite and, in the Mohican Formation, chloritoid are present in minor amounts. Chlorite, muscovite, epidote, light-green amphibole, and locally biotite are present in the volcanic rocks and greywackes of the Upper Index and Jowett Formations. The plagioclase in these rocks is oligoclase or andesine, and the textures of the clastic rocks suggest that the plagioclase has been unaffected by metamorphism. Minor biotite is found locally in the greywackes and volcanic rocks.

CHAPTER III.—STRUCTURAL GEOLOGY

The determination of structure has been one of the main purposes of this study. The structure of the Duncan Lake area is very complex, involving various styles of repeated folding. Patterns of folding found within the area have been recognized or suspected in other parts of the Kootenay arc, but nowhere else is the large scale of the structures and the over-all complexity more clearly displayed. Though many of the structures are well defined in the field, they are difficult to map and portray and difficult to describe. The ensuing descriptions may not everywhere be easy to follow, and in order to clarify them, simplified sketches and diagrams have been used. The cross-sections of Figure 4 show with minimum inference the structures determined in the field. The idealized cross-sections of Figure 16 best illustrate the magnitude of the folding and the final over-all pattern of rock distribution.

Complex folds dominate the structure of the Duncan Lake area. Many of the folds are strongly sheared, but faults in general are subordinate to the folds and many are closely related to them. Folds have been mapped in the field, and a pattern and sequence of folding has been determined by closely tracing and mapping formations, by studying minor and major structures where they are exposed, and through knowledge of the stratigraphic succession. Careful mapping is essential. Most of the folds have a low plunge and their cross-sectional form is outlined by mapping, especially on the walls of cross-cutting valleys, some of which have a relief of more than 4,000 feet. The slopes on the northern sides of these valleys are particularly instructive because the folds in general plunge at low angles to the north. Minor structures, principally small folds, foliation planes, and lineations, provide a means of determining the geometric form of the larger structures. A knowledge of the stratigraphy makes it possible to reconstruct folds which can rarely be seen in the field. Broad features of the stratigraphy are known from work in other parts of the Kootenay arc, particularly from the Ferguson area, but details of the stratigraphy have been worked out within the area only as the structure became known. Structural and stratigraphic detail are determined together, and the parts of the area in which the structure is least known are the parts in which the stratigraphy is still in doubt. Primary features, such as cross-bedding, graded beds, ripple marks, etc., which might be useful in determining structure are found only rarely in the map-area.

The folds which dominate the structure of the Duncan Lake area have developed over an extended period of time in response to the changing movement of rock masses. Little is known of the absolute age of the deformation or the length of time over which deformation took place. Several stages of deformation have been determined, all of which are considered to belong to one orogenic period, which is probably Mesozoic. Field studies have revealed parts of a sequence of deformation which are thought of as related phases of one long continuous process. The most important folds in the map-area belong to the two oldest known phases of deformation and are called Phase I and Phase II folds. Other folds belonging to later phases of deformation are known, but they are thought to be of local origin and of minor significance in the regional structure.

Emphasis in the following descriptions is on the structure as it may affect exploration. Replacement lead-zinc deposits in the Kootenay arc are largely in carbonate formations associated with one or more controlling structures. Repetition of these formations by folding, the detailed forms resulting from deformation, patterns of outcrop, and the recognition of structures which control mineralization are all important in exploration. Although the structures in the Duncan Lake area are complicated, structural patterns can be determined and mineralized structures can be recognized in areas of a size normally involved in exploratory work. It is hoped that the following account of the structure will provide a background for mining exploration as well as for more detailed geological work.

SUMMARY

The oldest folds recognized in the Duncan Lake area, called Phase I folds, are isoclinal and plunge at low angles to the north. Most of these folds cannot be seen directly, and are reconstructed only from careful studies of the distribution of the rock succession and the mapping of formations. Although they are not generally seen, some Phase I folds are exposed in individual outcrops or become obvious from the study of a number of closely spaced outcrops. The limbs and axial planes of these folds are curved and have been folded by Phase II structures. The principal Phase I folds in the map-area are the Howser syncline, the Duncan anticline, the St. Patrick syncline, and the Meadow Creek anticline (*see* Fig. 2). No well-defined faults clearly related to Phase I folds are recognized, although strongly sheared and pinched limbs of folds are common.

Phase II folds are more open than Phase I folds. They are clearly visible in many outcrops and are defined by the layering of the rocks and by the attitude of the formational contacts. The folds plunge mainly to the north and northwest at angles as great as 30 degrees, but most plunge between north 15 and 25 degrees west at 5 to 10 degrees. The plunge is known from the plunge of minor folds and the plunge of a prominent lineation. The largest Phase II folds include the Lavina synform,* the Comb Mountain antiform, the Glacier Creek synform, the Lake Creek antiform, and the Kootenay Lake antiform (*see* Fig. 10).

Slip is common parallel to cleavage planes of Phase II folds, and many small faults along these planes are known. Several larger faults are known, some of which may be related to the Phase II deformation. They strike north or west of north and dip steeply; commonly the apparent dip-slip is west side down and the strike-slip is thought to be small.

MINOR STRUCTURES

Structures small enough to be seen in one outcrop or a series of closely spaced outcrops, and referred to as minor structures, are present essentially everywhere in the Duncan Lake area. Only the most massive volcanic rocks of the Upper Index and Jowett Formations and thick parts of the Ajax Quartzite do not contain them. Many outcrops display so many minor structures that it is difficult in mapping on the present scale to analyse them and to interpret and record the significant ones. Experience in the map-area has shown that some minor structures are of more importance in determining the larger structures than others. Particular attention has been paid to the distinctions between Phase I and Phase II structures, and the purpose of the following discussion is to emphasize the characteristics of each set of structures. Many minor structures are of unknown significance, and a complete analysis of the minor structures has not been attempted.

FOLIATION

Foliation is used in this report as a general term referring to all closely spaced repetitive planar structures in rocks, the most common types being bedding, layering, cleavage, and schistosity. Cleavage is used in a descriptive sense to refer to the ability of a fine-grained rock to split into slabs or plates. Schistosity is the foliation of schists, and both cleavage and schistosity may describe the same structural feature.

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* A synform is a fold which in cross-section is concave or opens upward but in which the stratigraphic order of the rocks involved may be reversed or repeated. An antiform is a fold which in cross-section is concave or opens downward and in which the stratigraphic order of the rocks may be reversed or repeated.

To aid description, foliation planes are called first, second, and late foliations, although in the field it is not always possible to relate a particular foliation to a major phase of deformation. Foliation formed during or before the Phase I folding is called the first foliation. Foliation which is related to Phase II folds is called the second foliation, and other foliation planes which are clearly superimposed on the first and second are called late foliations.

The first foliation is mainly bedding and a schistosity parallel to it. Less commonly it is a closely spaced jointing or a layering which is parallel to bedding or to the formational boundaries. The schistosity is parallel to the bedding because the Phase I folds are isoclinal. Very few hinges of Phase I folds are seen, and the relationships between schistosity and bedding at the hinges are obscure because in the softer micaceous rocks the hinges are extremely attenuated, and in the harder rocks the schistosity is poorly developed.

The second foliation is a more or less well-developed cleavage or schistosity that commonly transects the first foliation. The second foliation is generally parallel to the axial planes of Phase II folds, but diverges from them in the more quartzitic and more heterogeneous sequences. The extent to which each type of foliation is developed varies from one rock type to another and from place to place within the map-area. Consequently it is not always possible to distinguish between first and second foliations. As a general rule, bedding and planar structures parallel to it are first foliations, and cleavage and schistosity crossing the bedding represent the second foliation.

The Marsh-Adams and Mohican Formations which contain beds of contrasting lithology display the most ideal sets of foliation planes. The two foliations can readily be seen in these formations in the Duncan anticline, between the peninsula in Duncan Lake and Glacier Creek, and on the upper south slopes of Comb Mountain. In the more quartzitic rocks the second foliation is a poorly defined cleavage, whereas in the more micaceous beds it is a fairly well-developed schistosity. Locally the second foliation in mica schists of the Mohican Formation consists of closely spaced

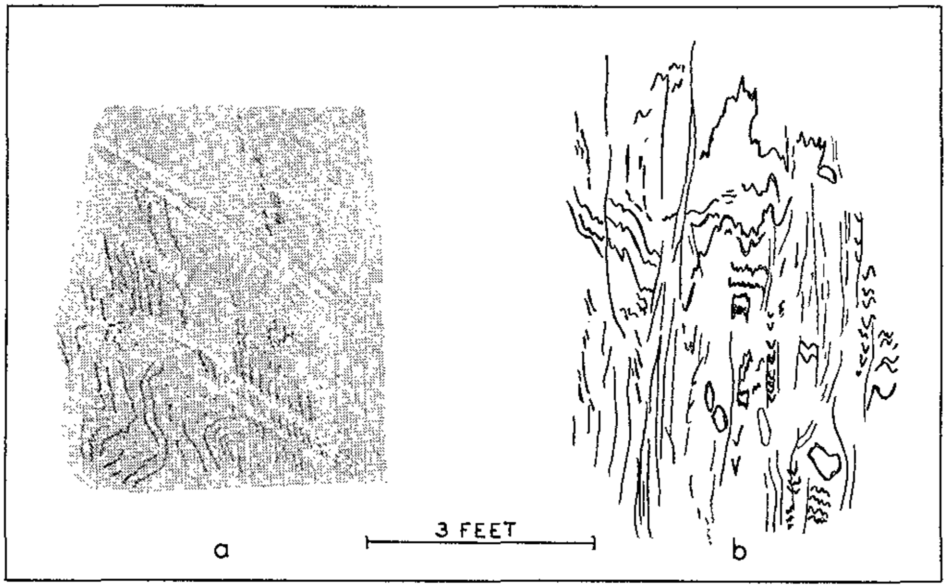

Figure 7. Sketches of foliations in limestones and schists: (*a*) contorted grey bands (beds?) and white layers (second foliation) in crystalline limestone exposed on cut face in marble quarry near Marblehead; (*b*) cleavage (vertical) and disrupted bedding in grey mica schists of the Index Formation.

planes of incipient shear along the sharply folded crests of chevron folds. In addition to exposures in the Marsh-Adams and Mohican Formations, both first and second foliations are also seen clearly in parts of the Triune, Ajax, and Sharon Creek Formations (Plate XIII) on Howser Ridge, and in quartzitic rocks in the Broadview Formation (Plate XII).

Foliation in rocks of the Index Formation is mainly schistosity; bedding is found only locally. Mainly the rocks are very fine grained and the schistosity consists of closely spaced micaceous or chloritic planes. Some of the grey rocks of the Lower Index have a strong slaty cleavage. Alternating calcareous and argillaceous layers a few inches thick constitute the bedding, but such layers are highly contorted and are commonly sheared and squeezed into lenses with little continuity (Fig. 7, *b*). In other places fairly continuous layers are parallel to a more or less well-developed schistosity. The identification of a schistosity or cleavage as a first or second foliation in these rocks is difficult. Experience has shown that in the Howser syncline the most prominent schistosity is the second foliation. On Howser Ridge and on the slopes northeast of the Lardeau River the most prominent foliation is probably also the second, although the first and also late foliations are fairly common. On Lardeau Ridge and in the southwestern belt the prominent schistosity may be either the first or second foliation.

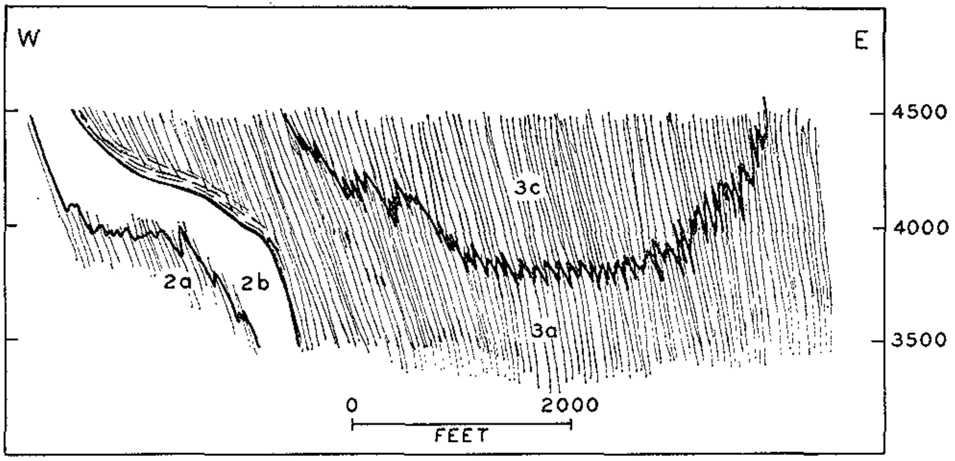

Figure 8. Cross-section of the Glacier Creek synform as exposed on the north side of Glacier Creek: (2*a*) Mohican, (2*b*) Badshot, (3*a*) Lower Index, and (3*c*) Upper Index Formations. Cleavage and schistosity dipping steeply to the east.

In the Index Formation the second foliation is clearly defined on a regional scale in the Howser syncline, where it commonly transects the first foliation, recognized mainly from the attitude of the formational boundaries. A clear, large-scale example of the second foliation transecting formational boundaries is found on Glacier Creek 2½ to 3 miles from the Duncan River (*see* Fig. 8). Dark-grey schists of the Lower Index Formation exposed along the canyon of Glacier Creek have a strong schistosity, the second foliation, which strikes about north 20 degrees west and is essentially vertical. These rocks pass upward along the schistosity planes into green schists of the Upper Index. Mapping of the contact between the Lower and Upper Index on each side of Glacier Creek outlines a gently plunging synclinal trough called the Glacier Creek synform, in which the steeply dipping schistosity is more or less parallel to the axial plane. In individual outcrops the first foliation is seen in the grey schists as a poorly defined layering which is so highly crenulated that remnants of thin limestone layers consist of rod-like masses with lenticular or hookshaped cross-sections. The contact between the grey and the overlying green schist, like the first foliation, is gently dipping in gross attitude but, because of complex large-scale crenulation, in detail is parallel to the steeply dipping schistosity which is the second foliation.

Foliation in the Badshot and in the limestone in the Mohican Formation consists mainly of alternating dark-grey and light-grey or white layers loosely described as colour banding. Colour banding is also present in some of the dolomites and siliceous dolomites, but it is much more pronounced in the limestones. In general the banding is parallel to formational boundaries and is a first foliation. In micaceous limestones, cleavage and micaceous layers are parallel to the banding and are also regarded as first foliation. The bands outline Phase II folds but tend to be destroyed by the Phase II folding and grade into a mottled texture at the fold hinges. Poorly developed axial-plane cleavage and parallel white layers are present locally near the hinges of these folds and constitute the second foliation. These structures are well displayed on smooth walls of the old lime quarries near Marblehead (*see* Fig. 7, *a*) but are rarely seen in natural exposures.

It is the attitude of the first foliation that defines the Phase II folds (*see* p. 42). Regional trends of the first foliation are shown diagrammatically on Figure 9. The attitude of the second foliation is locally quite variable, but on a regional scale it changes systematically in both strike and dip (*see* Fig. 10). The change is from a strike of about north 10 degrees west and a moderate westerly dip in the southern part of the area, steepening upward through a vertical dip, to a strike of about north 35 degrees west and a steep dip to the northeast at the northern end of the map-area. There is thus a vertical arc of curvature, concave to the west, and with a low plunge to the north. This arc is described best by rocks of the Howser syncline. It is also inferred in the southwestern belt and the northern end of Kootenay Lake, where the attitudes of the second foliation are more variable and less well known.

MINOR FOLDS

Most of the minor folds seen in the Duncan Lake area are second- or late-phase structures; Phase I minor folds are not commonly seen.

Two of the best-known examples of minor Phase I folds are shown in Plates XVI and XVII. Minor Phase I folds are isoclinal, their hinges are rarely seen, but where exposed they plunge to the north at low angles. Fold hinges in Plate XVI are rounded, but in more schistose rocks they are sharp and are obscured by the schistosity. In several places where large Phase I folds are known or suspected, it has been shown that the cross-sectional shapes of minor Phase I folds bear a true dragfold relationship to the next larger folds. The axial planes of the minor Phase I folds are folded on axes essentially parallel to the axes of the Phase I folds themselves.

Phase II minor folds are relatively open structures outlined by the first foliation. Many of these folds in micaceous quartzites have cleavage parallel to or almost parallel to the axial planes. In purer quartzites, closely spaced jointing, or fracture cleavage, is parallel to or fans outward from the axial plane. In mica schists of the Mohican and locally of the Index, first foliation schistosity is folded or intricately crenulated in either rounded or sharp-crested folds. Most of the Phase II minor folds can be used as dragfolds to predict the direction toward which the crest of the next larger Phase II fold is to be found. The plunge of the minor Phase II folds is at low angles to the north and is statistically parallel to the axes of major Phase II folds. It is also parallel to the plunge of the most prominent lineation.

Minor folds that are not clearly identified as belonging to the first or second phase of deformation occur from place to place. In general they have a relatively steep plunge and produce an abrupt change in the otherwise uniform strike of the rocks. They are commonly Z-shaped in plan. East of the north end of Kootenay

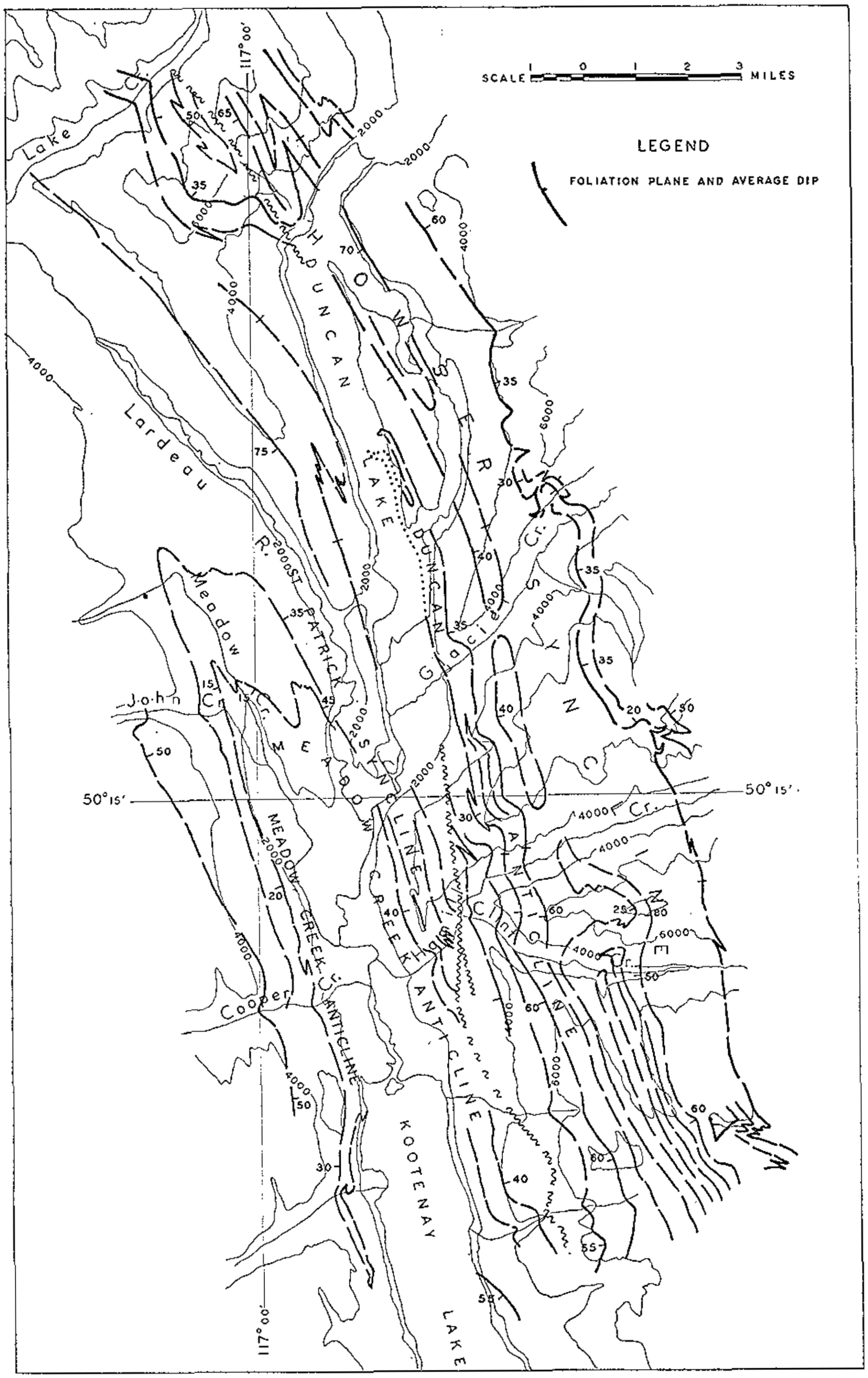

Figure 9. Generalized sketch-map showing formational (first foliation) trends and attitudes.

Lake, folds of this sort plunge west and northwest at angles of 25 to 45 degrees. On the east slope of Howser Ridge, schists of the Upper Index are crenulated about axes which plunge northwest at 30 to 60 degrees (Plate XIV). The crenulations produce chevron folds and a poorly developed axial-plane cleavage which strikes about north 70 degrees west and dips to the north. It is not known whether all these folds that are alike in form and attitude belong to one genetically related set of folds. No major structures with which they may be associated are recognized. They are late structures and are not distinguished from other late minor folds which have a variety of attitudes and shapes and are seen from place to place throughout the area.

LINEATION

Most of the rocks of the area show linear structures produced by small wrinkles, crenulations, alignment of mica flakes, or the intersections of foliation planes. Essentially all these lineations are related in origin and most have been produced by the folding. Most outcrops display only one lineation that is parallel to the fold axes, as can be seen in many outcrops of the Marsh-Adams and Mohican Formations. It is considered to be a product of the Phase II folding. At places two or more non-parallel lineations are present. Usually one is more pronounced than the other, and the pronounced lineation is parallel to the Phase II axes. In some places, particularly on the western limb of the Duncan anticline, a fine lineation resulting mainly from oriented mica flakes lies at an acute angle to the most pronounced lineation and is folded by Phase II minor folds. This lineation is regarded as a Phase I structure, which at most places is parallel to the Phase II lineations and indistinguishable from them. In general, lineations in schists of the Index Formation are much more complex than they are in the quartzitic sequences. Two or more lineations are particularly common on lower Howser Ridge and northwest to Lake Creek. The plunge is variable and the identification of first, second, and late-phase lineations is difficult.

PHASE II FOLDS

Phase II folds are the most prominent folds in the map-area. They are described first because Phase I folds cannot be described clearly without reference to them. Phase II folds are relatively open structures outlined by the first foliation and by formational contacts. They plunge to the north and northwest at low angles. The axes are defined by the most pronounced lineation, the axes of minor folds, and the attitudes of first foliation planes. In the southern part of the area the average plunge is north 15 degrees west at 10 degrees, and in the northern part of the area it is north 35 degrees west at 10 degrees. The axial planes of the Phase II folds in the southern part of the area dip at moderate to steep angles to the west, and in the northern part dip steeply to the east and to the west. The following descriptions give examples of these general relationships. The best-known major Phase II folds are the Comb Mountain and Kootenay Lake antiforms and the Glacier Creek synform. The Lavina synform and antiform are somewhat smaller Phase II structures, and the Lake Creek antiform is poorly defined and not well known (*see* Fig. 10).

COMB MOUNTAIN ANTIFORM

The Comb Mountain antiform is well exposed on the steep south slope of Comb Mountain, a slope containing many rock bluffs largely cleared of trees by fire and having a maximum relief of 4,500 feet. The core of the antiform is composed of quartzite of the Marsh-Adams Formation, and the limbs are defined by the overlying Mohican and lower part of the Index Formations. The fold, outlined by buff- and white-weathering schists and dolomites of the Mohican Formation, is clearly visible

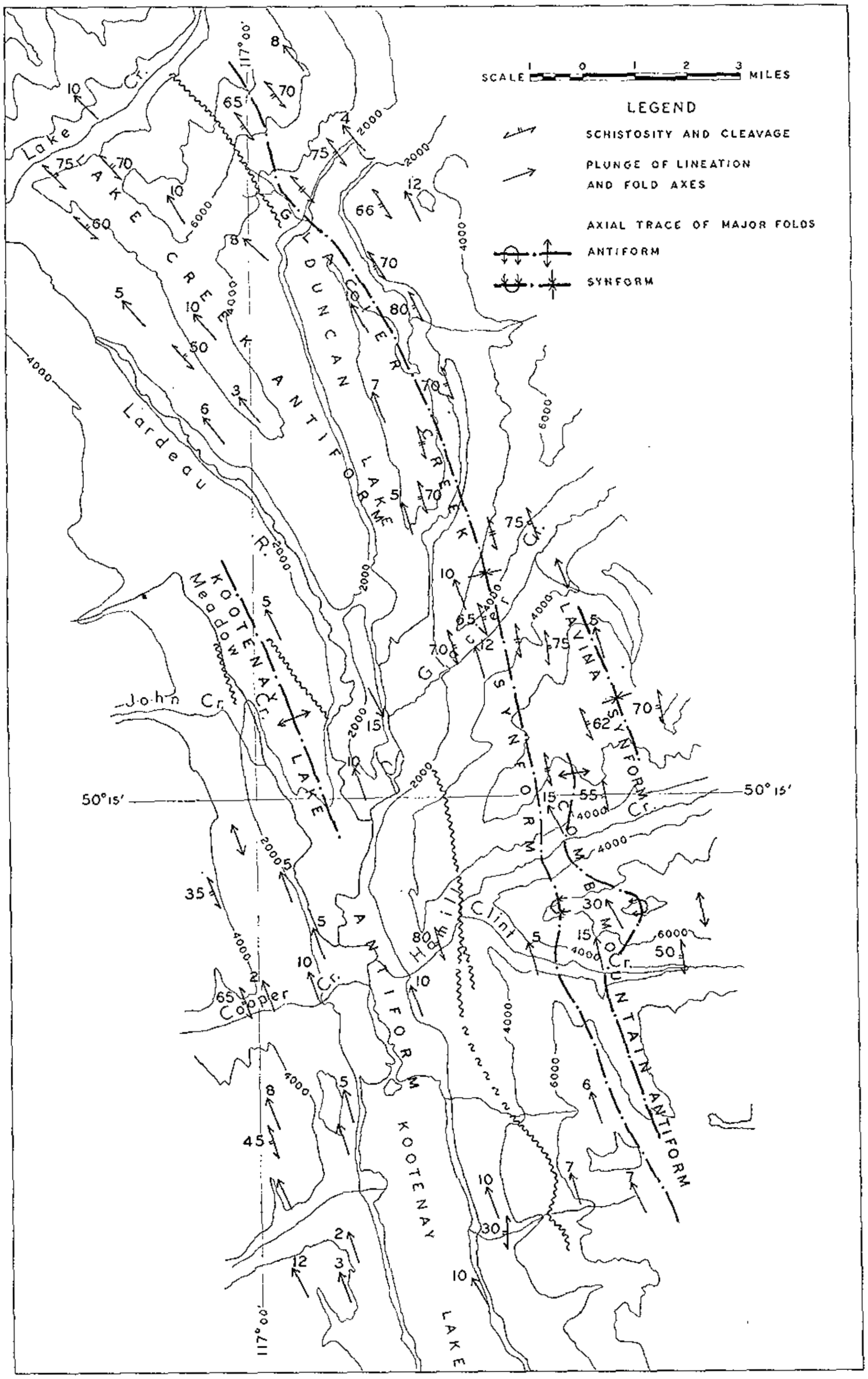

Figure 10. Generalized map of Phase II structures.

in any view of Comb Mountain from the south (*see* Plate VII and Fig. 11). The western limb has a low cumulative dip to the west, resulting from a series of relatively large step-like folds rising to the east. The eastern limb is not complicated by such folds, but dips more or less uniformly to the west. At higher elevations the dip is 70 to 80 degrees, and on the lower slopes it flattens to 65 degrees to the west.

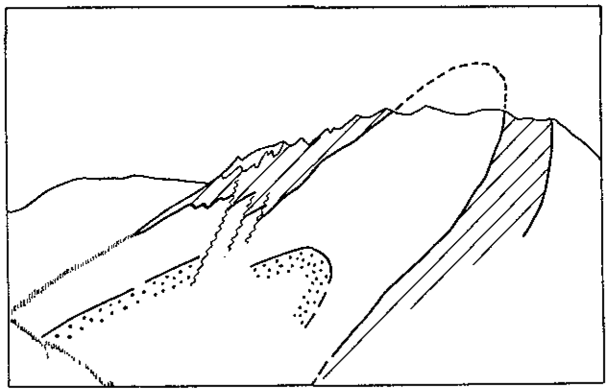

Figure 11. Sketch from photograph (Plate VII) of Comb Mountain antiform from the south. Dot pattern—white quartzite in Marsh-Adams Formation; oblique lines — Mohican and Badshot Formations.

The large folds on the western limb are outlined in a striking manner on the upper slopes of the mountain by the base of the Index, by calcareous layers in the Mohican, and by quartzites of the Marsh-Adams Formation. The folds are open, with relatively straight limbs and sharply curving hinges. The folds have the form of dragfolds on the western limb of the antiform. They have a moderately well-developed axial-plane cleavage which strikes north 10 degrees west and dips 45 to 60 degrees to the west. Slip on the cleavage planes has produced a series of westerly dipping reverse faults, which are most prominent in the quartzites. The axes of the folds and of lineations and minor folds associated with them plunge between north and northwest at angles ranging from 5 to about 30 degrees. The average plunge of the Comb Mountain antiform from the top of Comb Mountain to the north side of Hamill Creek, as inferred from surface trace of the top of the Marsh-Adams Formation, is northwest at 25 to 30 degrees.

No clearly defined Phase I folds have been found on the south face of Comb Mountain, but lenticular masses of dolomite lying parallel to the formations are probably remnants of Phase I isoclinal folds. A major Phase I fold is indicated by a reversal of the stratigraphic order on the lower slopes of the mountain and in the south fork of Clint Creek to the south. The stratigraphic succession on Comb Mountain is right side up and extends downward to blocky white quartzites just below the Marsh-Adams Formation. The stratigraphic succession along the south fork of Clint Creek is upside down: in the core of the antiform the Mohican Formation exposed in the bottom of the valley lies beneath Marsh-Adams quartzites. This stratigraphic reversal is almost certainly caused by an isoclinal Phase I fold which, from regional considerations, appears to be part of the Duncan anticline (*see* p. 58 and Fig. 16).

To the north the relatively steep plunge of the Comb Mountain antiform causes the Marsh-Adams and Mohican Formations on the crest of the antiform to pass beneath the Index on the lower slopes north of Hamill Creek. The plunge also produces a complex pattern of outcrops south of Hamill Creek, where the plunge of the fold is approximately parallel to the average slope of the hill and where the topography is very irregular in detail. North of Hamill Creek the antiform is within grey schists, argillites, and slates of the Lower Index. Judging from the cleavage and schistosity, the dip of the axial plane steepens upward from about 50 degrees westward near Hamill Creek to vertical or steeply east on Lavina Ridge. Lineations suggest a low plunge to the north. The shape of the antiform has not been defined by any markers within the Index, and it is not certain that the structure continues as far as the northern edge of the map-area. The steeply dipping schistosity and the low north-plunging lineations persist.

South of Comb Mountain the antiform is exposed only as sub-parallel layers of Marsh-Adams and Mohican Formations. They dip at moderate angles to the west, and it is concluded that the antiform is somewhat tighter than to the north and is sheared by west-dipping strike faults parallel to the axial plane. The crestal zone of the antiform is exposed in the pass at the head of the south fork of Clint Creek. In general it appears that the plunge of the antiform is lower north and south of Comb Mountain than it is on the mountain itself. On Comb Mountain the plunge steepens and swings in azimuth toward the northwest.

Glacier Creek Synform

The Glacier Creek synform lies west of the Comb Mountain antiform. As exposed it is mainly within fine-grained schists of the Index Formation, and consequently is not clearly defined by markers. South of Hamill Creek the Mohican Formation is exposed on both limbs; north of Hamill Creek the trough of the synform is outlined by the contact between the grey schists of the Lower Index and the green schists of the Upper Index. Probably a significant strike fault lies along the eastern limb throughout this area. South of Hamill Creek the axial plane dips 50 to 60 degrees to the west and the fold is almost isoclinal. Between Lavina Ridge and the north side of Glacier Creek the trough of the synform is rounded and is transected by a steeply dipping schistosity parallel to the axial plane of the fold (*see* p. 44 and Fig. 8). The average plunge of the trough is north 15 to 20 degrees west at about 10 degrees.

To the north the axial plane continues to dip steeply and the axis, as indicated by the lineations, to plunge at low angles northward. North of Duncan Lake the synform as defined by the contact of the Lower and Upper Index schists is nearly isoclinal (*see* Fig. 15). A highly cleaved wedge of grey schists of the Lower Index in reversed stratigraphic order above green schists of the Upper Index is contained in the trough of the synform northeast of Gallop Creek. The schists dip steeply to the southwest, and the grey schist feathers out into the green at the hinge of the fold in Gallop Creek.

East of this wedge of grey schist is a complimentary wedge of green schist which tapers upward and ends just at the crest of Howser Ridge. This wedge is probably the overturned trough of the Howser syncline, a major Phase I fold, on the eastern limb of the Glacier Creek synform (*see* p. 56).

Kootenay Lake Antiform

The fold here named the Kootenay Lake antiform was originally described by Walker and Bancroft (1929, p. 16) as "an anticlinal arch spanning the valley of Kootenay Lake." The over-all form of the fold can be inferred only from integrating observations over relatively great distances on both sides of the valley (*see* Fig. 12). A crestal region of low dips is exposed north of Kootenay Lake and in bluffs northwest of Marblehead, where the antiform appears as an open upright fold plunging to the north. The eastern part of the fold is exposed along the east side of Duncan Valley and Kootenay Lake and in the canyon of Hamill Creek; the western part is well displayed in the Lardeau Bluff and canyons of Davis and Cooper Creeks. The plunge of the fold is indicated by a strong and uniform lineation and by the plunge of minor folds and is north 15 to 20 degrees west at 5 to 10 degrees. The rocks in which the fold is defined are mainly quartzites of the Marsh-Adams, limestones of the Badshot, and grey mica schists of the Lower Index Formations. Minor folds, some of which have amplitudes as great as a hundred feet, are common in the quartzitic rocks but are rarely seen in the limestones and schists. Banding and mottled textures are seen in the limestones, and a more or less well-developed, irregularly crenulated schistosity is seen in the schists.

In the crestal region northwest of Marblehead the formations have regular dips ranging from 25 to 55 degrees eastward, east of the crest, and from 10 to 30 degrees westward, west of the crest. The axial planes of minor folds in the east-dipping layers dip eastward somewhat more steeply than the formations, near the crest they flatten, and in the west-dipping layers they dip westward, commonly at a lower angle than the formations (*see* Fig. 12, *b*, *c*, and *d*). In the quartzitic rocks a poorly defined cleavage more or less parallel to the axial planes of the folds is locally present. In the limestones and schists the dominant foliation is parallel to formational boundaries, but locally a banding parallel to axial planes of minor folds can be seen (Fig. 7, *a*). The minor folds, where completely known, have an asymmetry suggestive of a relative movement of the upper layers westward over the lower ones. The crestal region of the antiform can be followed northward to near the Lardeau River at Goldhill.

In the eastern part of the antiform north of Hamill Creek the formations dip at moderate angles to the east, but in Hamill Creek and on the hills north of Argenta the formations locally steepen through vertical to steeply west, and south of Argenta the dominant dip is to the west. On the north slope of Hamill Creek the axial planes of minor folds dip steeply, and in the canyon they are marked by a poor cleavage dipping to the west. Farther south, where the beds dip westward, the dip of the cleavage is lower than the dip of the beds.

The western part of the Kootenay Lake antiform exposed on the Lardeau Bluff and in Davis Creek is in the hinge zone of a major Phase I fold, the Meadow Creek anticline, and there are many Phase I digitations. Because of this special structural position and because the Lardeau Bluff cuts obliquely across the structures, outcrop patterns are very complex (*see* Plate XIX). Minor folds related to the Kootenay Lake antiform are well displayed in quartzitic rocks, and larger folds are outlined by the formations themselves. The west-dipping formations on the western limb in the crestal region of the antiform turn abruptly downward in the Lardeau Bluff in a series of folds with axial planes dipping at low angles to the west. Folds of this sort range from a few inches across to folds in which the axial planes are several hundred feet apart. In the quartzites and adjacent limestones they are attenuated folds with more or less well-rounded hinges. Large folds of the same sort outlined by the Badshot-Index contact in Cooper Canyon and by green and grey schists of the Index Formation north of Davis Creek have sharp hinges and strongly sheared limbs (*see* Fig. 4).

The outlines of the Kootenay Lake antiform shown diagrammatically in Figure 16 are inferred by projecting, parallel to the plunge, the elements just described onto one plane. Probably the form of the fold changes somewhat along the plunge. It is thought that it becomes tighter toward the south, but the crestal region coincides with the lower Duncan Valley, and Kootenay Lake and is not exposed. A large overturned antiform with axial plane dipping at moderate angles to the west is exposed near the mouth of Salisbury Creek and may be characteristic of the crestal region in this area. If so, it is tighter and more asymmetric than the fold near Marblehead.

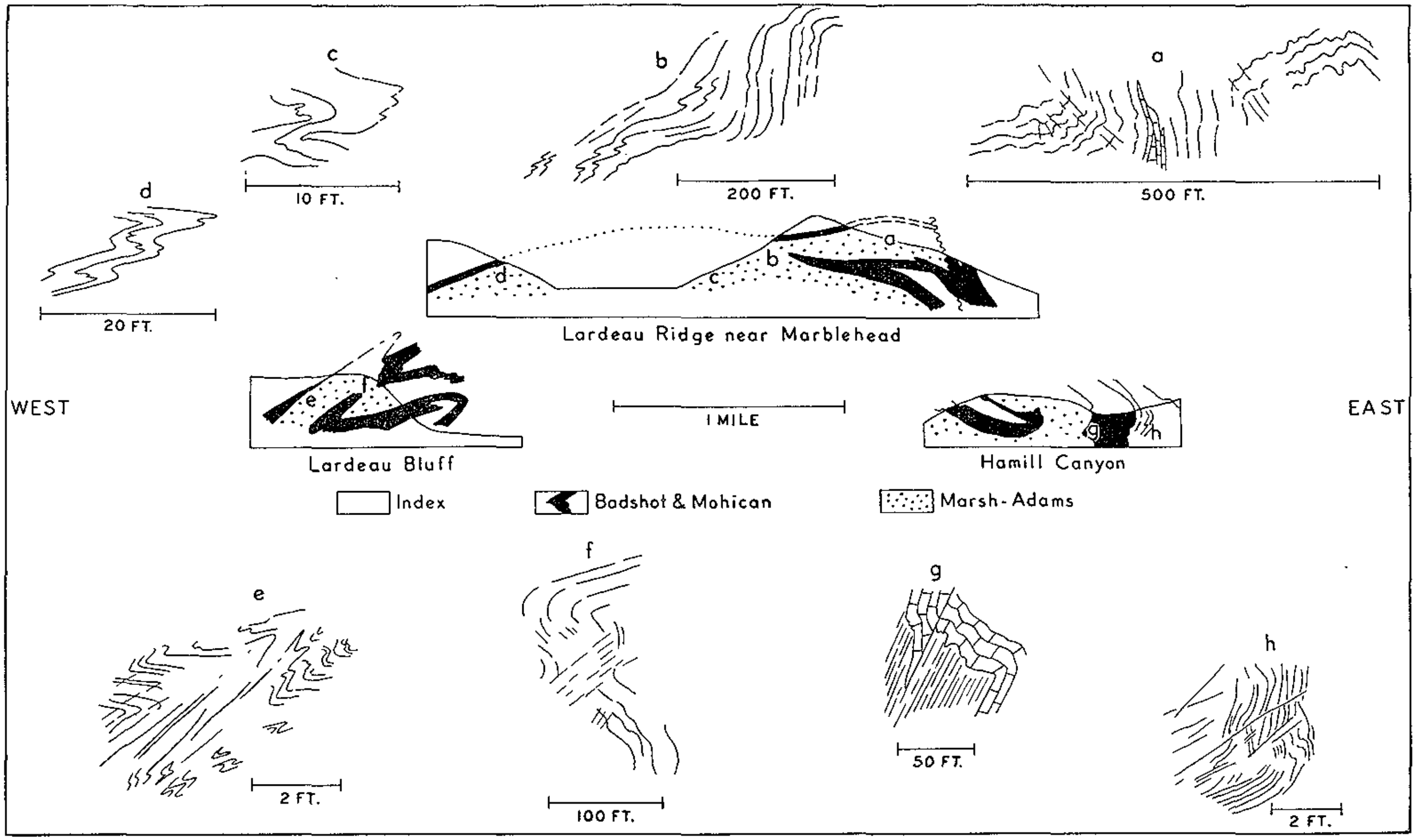

Figure 12. Elements of the structure of the Kootenay Lake antiform. Diagrammatic cross-sections: Lardeau Ridge near Marblehead (crestal zone); Lardeau Bluff (western part); Hamill Canyon (eastern part). Field sketches *a* to *h* of folds characteristic of the various parts. Vertical and horizontal scales equal.

Structure West of the Kootenay Lake Antiform

Knowledge of the structure west of the Kootenay Lake antiform is fragmentary. In general the rocks of the Index and younger formations which lie west of the antiform are difficult to study structurally. Some fairly large folds have been defined in the valleys of Davis, Cooper, John, and upper Meadow Creeks, but they have not been satisfactorily integrated.

Near the antiform the dominant schistosity in the Index Formation dips at low angles to the west and is essentially parallel to the formations. Between Davis Creek and John Creek it is locally transected by a cleavage dipping at moderate angles to the west. This cleavage, which is a second foliation, is present also in the Jowett and Broadview Formations. In the Broadview it commonly transects the bedding (*see* Plate XII) and locally is more or less parallel to the axial planes of minor Phase II folds. In the upper part of Meadow Creek a cleavage that also appears to be a Phase II structure dips at steep to moderate angles to the east, and in the Jowett Formation is parallel to the axial planes of large as well as small Phase II folds (*see* Fig. 4, section D-D′).

No folds that are certainly Phase I structures are known west of the Kootenay Lake antiform. On the steep north slopes of Cooper and Davis Creeks, the trace of the bottom of the Broadview Formation shows a series of folds that are sharp-crested and very attenuated. They may be Phase I folds, or more probably they are Phase II folds attenuated by slip on planes parallel to the Phase II cleavage. In general it appears that Phase II structures west of the Kootenay Lake antiform have a low plunge and have axial planes which in the southern part of the area dip to the west and which in the northern part dip to the east. Though not fully confirmed in the field, it is probable that the reversal from westerly to easterly dipping axial planes takes place through the vertical.

PHASE II FOLDS IN THE EASTERN BELT

Several large Phase II folds are found along the eastern belt that clearly show the relationships between first- and second-phase folds. They are exposed mainly between the southeast corner of the map-area and the slope north of Glacier Creek in rocks of the Marsh-Adams and Mohican Formations and are seen best on the northern slopes of the valleys and in alpine country on Lavina Ridge and south of Clint Creek.

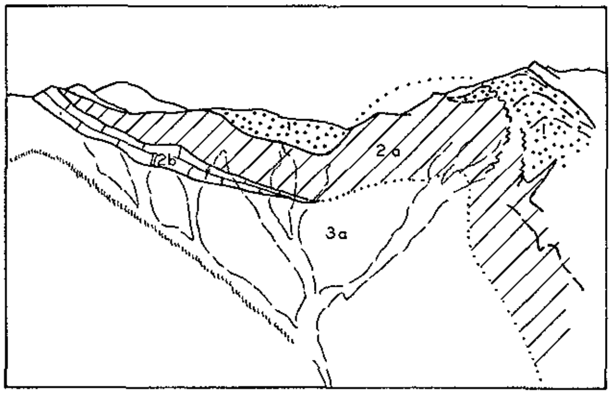

Figure 13. Sketch from a photograph (Plate VIII) showing Lavina synform and antiform as seen looking north across Hamill Creek. (1) Marsh-Adams Formation; (2*a*) Mohican Formation; (2*b*) Badshot Formation; (3*a*) Lower Index Formation.

Two open Phase II folds known as the Lavina synform and Lavina antiform are exposed on Lavina Ridge 2 to 3 miles east of Lavina Lookout. The synform is clearly defined by the Badshot and Mohican Formations on the upper slopes south of the ridge (*see* Plate VIII). The stratigraphic succession involved in the fold is overturned; quartzites of the Marsh-Adams Formation are contained in the trough and lie above the stratigraphically higher Mohican, Badshot, and Index Formations. Lineations and minor folds indicate that the synform plunges north 20 degrees west at 5 degrees. A moderately well-developed schistosity in the Mohican schists on the western limb of the synform dips 60 to 70 degrees to the east and dips more steeply to the east than the formations. On the eastern limb the second foliation dips steeply to the west. The Lavina antiform lies east of the synform (*see* Fig. 13). It is seen best in quartzites at the eastern edge of the map-area and has a low plunge to the north and a fairly well-defined axial-plane cleavage dipping 65 to 75 degrees to the west. Slip on the cleavage planes has produced a number of relatively small west-dipping faults.

The Lavina synform and antiform have not been identified with certainty north of McLeod Creek. To the south the antiform appears to become smaller, and the synform is obscure in schists of the Index Formation. Both the synform and the antiform have clearly exposed small Phase I folds associated with them. The most obvious are synclinal wedges or tails of the Mohican Formation which project eastward or downward into the Marsh-Adams. Two are exposed on the eastern limb of the Lavina synform on the upper slopes south of Lavina Ridge, and the lower one is illustrated on Figure 13 (*see also* p. 56). Another is present on the more northerly of two 7,500-foot summits west of McLeod Creek.

Two Phase II folds smaller than the Lavina synform and antiform, and like them in form, are found in the upper part of the slope north of Glacier Creek. Their axial planes dip steeply to the west, and the folds have a very low plunge. An attenuated Phase I anticline with Marsh-Adams Quartzite in the core and two synclinal wedges of the Mohican Formation are involved in the Phase II structures, and together they produce a complex outcrop pattern. A generalized cross-section is given on Figure 14.

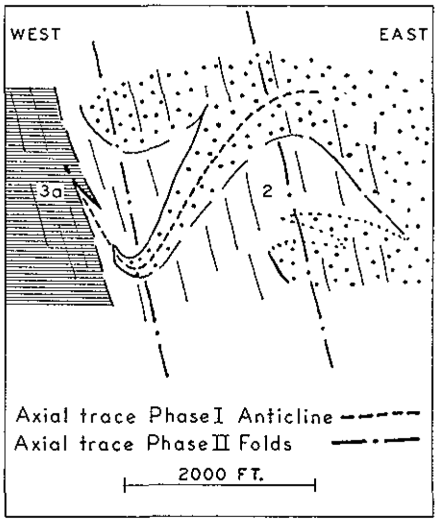

Figure 14. Idealized cross-section of Phase I and Phase II folds exposed on the north side of Glacier Creek: (1) Marsh-Adams Formation; (2) Mohican and Badshot Formations; (3*a*) Lower Index Formation.

In the southeastern corner of the map-area two large Phase II folds are exposed in alpine country east of Mount Willet. They are illustrated in Plate XX. Details of the folds are obscured in places because the metamorphism has made it difficult to distinguish garnet mica schists in the Index Formation from those in the Mohican, but the general forms of the Phase II folds are clear. They consist of a fairly tight synform to the west of a more open antiform. In Plate XX the lenses of limestone on the left side of the photograph are " on plunge " from the observer; the folds on the right are foreshortened. The point marked A is near the crest of the antiform, and B is on the western limb of the synform. The hinge of the synform cannot be seen in the photograph and is obscure also on the ground. The axial planes of the folds dip steeply to the west. The plunge of the minor structures is highly variable, but the average plunge of the minor structures and probably also of the larger folds is north 15 degrees west at angles of less than 5 degrees. Slip on schistosity planes more or less parallel to the axial planes of the major folds has resulted in obscure faults, some of which transect the strike of the layers at acute angles. One such fault probably truncates the limestone shown at A on Plate XX, and others are almost parallel to the lenses and layers of limestone at B. Many of the limestone lenses on the east are parts of Phase I folds which are isoclinal; ideally they consist of synclinal wedges of limestone and schist pinching out eastward and downward in micaceous quartzites of the Marsh-Adams Formation and anticlinal wedges of limestone pinching out upward or toward the west in schists of the Mohican or Index Formations. The area shown in Plate XX is close to the hinge zone of a major Phase I fold, the Howser syncline. The complex outcrop patterns in this area result from the coincidence of this zone and the two large Phase II folds.

LAKE CREEK ANTIFORM

The Lake Creek antiform is inferred from the distribution of rocks in the Index and overlying formations and from minor structures and larger folds within these rocks. Although the existence of the antiform is fairly certain, details of its form, internal structural, and local stratigraphic relationships are interpretive and based mainly on map patterns and an analysis of minor structures. A more complete understanding of the antiform and of a synform which almost certainly lies to the southwest of it may be gained by continued mapping to the northwest, beyond the present map-area.

Rocks of the Index Formation near the contact between the Upper and Lower Index, as exposed on the east slope of Howser Ridge due west of Jubilee Point and extending across Lake Creek to Mount Johnson a mile or so beyond the map-area, are clearly on the northeastern limb of the antiform. Many small and several moderately large tight folds with axial planes dipping to the northeast and with gently plunging axes have, when considered as dragfolds, a form indicating that an anticlinal axis lies to the southwest. Southwest of this zone of clearly marked folds is a sequence of schists, limestones, and quartzites with a persistent schistosity dipping on an average 70 degrees to the northeast, and with a poorly defined lineation plunging at low angles, principally to the northwest. Very few folds are seen in these rocks, but it is inferred, from the fact that probably no more than a few hundred feet of stratigraphic section is present across a belt more than a mile wide, that the rocks are repeated many times by gently plunging tight folds. A thin wedge of Ajax Quartzite on the north side of Lake Creek about 1½ miles from its mouth is almost certainly on the western limb of the antiform. Studies by Mathews (1953) in rocks of the Index Formation on Mount Johnson immediately northwest on strike from the present map-area defined an antiform which is almost certainly the Lake Creek antiform. Undoubtedly much of the repetitive folding belongs to the first phase of deformation, but the persistent northeasterly dipping schistosity is certainly the second foliation, and most of the folds seen in this belt resemble Phase II structures. The major anticlinal structure is regarded as a Phase II fold, the Lake Creek antiform.

PHASE I FOLDS

The Phase I folds are more complex and less well known than the Phase II folds. They are isoclinal, and have been folded by the Phase II deformation about axes essentially parallel to the Phase I fold axes. The Phase I folds are recognized largely from repetitions of the stratigraphic succession and from the regional distribution of the formations. The major Phase I folds have resulted in as many as 10 repetitions of the same stratigraphic succession across the southern part of the area, and the over-all northerly plunge causes successively younger formations to be exposed in going from south to north.

Detailed mapping has shown that the limbs of the folds are essentially parallel and the hinges are relatively sharp. The locations of only a few hinges of Phase I folds are known, and the hinges of the major folds are rarely seen. The folds are extremely attenuated, and it is difficult to determine in which direction they open. The limbs are stretched and sheared, and in several folds they are pinched off entirely, leaving large lenses of rock with attenuated tear-drop cross-sectional form (*see* Fig. 12). The folds tend to make rock units lenticular, and the axes along which the rock units pinch are theoretically parallel to the fold axes. Extreme attenuation, strong shearing, and lenticularity resulting from other phases of deformation, however, makes this generalization difficult to apply.

On a regional scale, Phase I folds are significant in exploration, mainly by causing repetition of certain rock types which may be favourable for mineralization. On a local scale, such as might be considered in mining or in a study of a few mineral claims, Phase I folds are of little significance.

Much of what is known of the form of the Phase I folds is interpreted from the geological map. A few Phase I folds have been observed which give direct evidence of their form. The general characteristics of the minor folds are described on page 45 and a few minor folds are shown in Plate XVI. Several somewhat larger clearly marked Phase I folds are known. Mostly they are exposed in the eastern belt at the top of the Marsh-Adams and within the Mohican Formation. One of the most clearly defined is an inverted syncline on the north side of Hamill Creek between elevations of 6,500 and 7,000 feet at the eastern edge of the map-area (*see* Fig. 4, section G-G′). It consists of a wedge of Mohican schists and limestones in Marsh-Adams Quartzite dipping to the west and thinning upward to the east. The hinge of the fold in the limestone at the base of the Mohican is shown in Plate XVII. Within the limestone and the underlying quartzite, the fold can be seen only locally. At most places the layers which constitute the first foliation are essentially parallel to one another and to the formational boundaries. Small Phase II folds warp the layers, and a Phase II cleavage transects them. In Plate XVII this cleavage is seen only in the quartzites, where locally it contains lenses of vein quartz. The rocks are on the western limb of an upright Phase II antiform, the Lavina antiform, plunging gently to the north. The Phase I fold is an inverted syncline and opens downward to the west.

On the north side of Glacier Creek between elevations of 3,500 and 5,500 feet, about a mile northeast of the Surprise mine, is a Phase I inverted anticline of quartzite of the Marsh-Adams in limestone and schist of the Mohican Formation. In most places the anticline appears as a westerly dipping layer of quartzite several hundred feet thick in Mohican limestones and schists. Traced eastward and upward along the slope, it gradually thickens and eventually joins the main mass of the Marsh-

Adams Formation to the east. Traced westward down the slope, the layer of quartzite passes around the trough of a Phase II synform and eventually pinches out within an easterly dipping series of Mohican limestones and schists. The Phase I anticline and associated folds inferred from rather fragmentary data are shown diagrammatically in Figure 14.

Other relatively small Phase I folds are known in the eastern belt, particularly on the north side of Clint Creek and in the mountains south of Clint Creek (*see* Plate XX). They are seen locally to the west, particularly on the western slopes of Mount Willet, in the canyons of Hamill and Bulmer Creeks, and on the north side of Davis Creek, where they appear to be somewhat more attenuated than in the eastern belt. These few " visible " Phase I folds give the basis of form inferred for the major Phase I folds described in the following paragraphs.

HOWSER SYNCLINE

The Howser syncline, which lies along the eastern side of the map-area, is named from Howser Ridge, where it is clearly defined by the Broadview, Sharon Creek, Ajax, and Triune Formations. It lies east of the Duncan anticline and west of a series of steeply dipping Hamill quartzites, largely beyond the map-area, in which the structure is complex and virtually unknown. Throughout most of the map-area the syncline contains schists of the Index Formation in the trough, flanked by the Badshot, Mohican, and Marsh-Adams Formations on the limbs. On Howser Ridge the Index is on the limbs, and the Broadview, Sharon Creek, Ajax, and Triune Formations are in the trough. The Howser syncline has been folded by Phase II structures, the largest of which are the Comb Mountain antiform and the Glacier Creek synform.

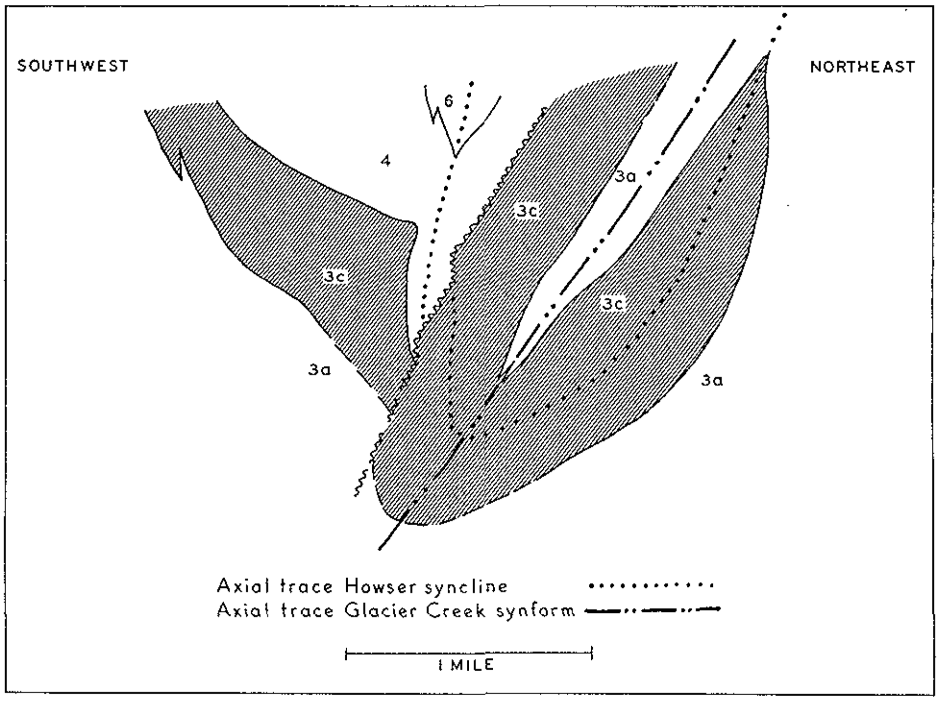

Figure 15. Idealized composite section showing the Howser syncline folded by the Glacier Creek synform. Northwest slope of Duncan Lake. (3*a*) Lower Index Formation; (3c) Upper Index Formation; (4) Triune, Ajax, and Sharon Creek Formations; (6) Broadview Formation.

On Howser Ridge the Howser syncline in rocks between the Triune and Broadview Formations is on the western limb of the Glacier Creek synform (*see* Figs. 15 and 16). A strike fault of unknown but probably small displacement lies along the northeastern side of these formations, separating them from rocks of the Index Formation, in which folds are outlined by the contact between the Upper and Lower Index. In these rocks the Howser syncline is folded around the trough of the Glacier Creek synform. On the eastern limb of the Glacier Creek synform, the Howser syncline is inverted and is defined by a wedge of the Upper Index green schist which tapers upward and pinches out near the crest of Howser Ridge. To the south the axial zone of the syncline is not defined, but, judging from the relationships on Howser Ridge and the position of the Comb Mountain antiform on Hamill Creek, the axial zone coincides with the most easterly band of the Lower Index along the eastern edge of the map-area. The Howser syncline continues in Lower Index rocks beyond the southeast corner of the map-area. The map pattern suggests a regional parallelism between the axes of the Howser syncline and those of the Glacier Creek synform and Comb Mountain antiform.

DUNCAN ANTICLINE

The Duncan anticline is adjacent to and west of the Howser syncline, and contains Marsh-Adams Quartzite in the core and rocks of the Mohican, Badshot, and Lower Index Formations on the limbs. The anticline has been traced from the southern edge of the map-area across Mount Willet and Hamill and Glacier Creeks to the peninsula on the eastern side of Duncan Lake. The anticline plunges to the north, and Duncan Lake is thought to cover the place where the hinge zone in the Badshot and Lower Index Formations plunges beneath the surface. West of Duncan Lake the anticline is obscured by complex Phase II structures in schists of the Index Formation.

Between the southern edge of the map-area and the peninsula in Duncan Lake, the Badshot, Mohican, and parts of the Marsh-Adams and Lower Index Formations are repeated symmetrically across the axial zone of the Duncan anticline. At many places, particularly on the south slope of Mount Willet, the sequence of members in these formations is virtually complete and in normal stratigraphic relationship on either limb of the fold. The axial plane of the anticline between Lavina Ridge and Duncan Lake dips at moderate angles to the east. On the peninsula it is folded by two open Phase II structures—an anticline lying east of a syncline—both of which are exposed in outcrops at the southern end of the peninsula. On the north slope of Hamill Creek the axial plane of the Duncan anticline steepens to vertical, and south of Hamill Creek it dips at moderate angles to the west. The plunge of the Duncan anticline is to the north, and, judging from the folding of lineations by minor Phase II folds in the Marsh-Adams Quartzite on the western limb of the anticline, the plunge is somewhat lower than the plunge of the Phase II folds.

The Duncan anticline is thought to be folded by the Glacier Creek synform and the Comb Mountain antiform. This interpretation is shown diagrammatically in Figure 16. The Index, Badshot, and Mohican Formations on the upper slopes of Comb Mountain correspond to the eastern limb of the anticline in the area between Mount Willet and the peninsula in Duncan Lake. These formations are more or less continuous around the trough of the Glacier Creek synform in exposures just south of the southern edge of the map-area. The Mohican Formation exposed along the south fork of Clint Creek (*see* Fig. 3) is thought to correspond to the Mohican Formation on the western limb of the Duncan anticline in the Mount Willet-Duncan Lake belt, but this has not been proved by mapping.

West of the Duncan anticline and south of Glacier Creek is a belt, bounded on the west by the Argenta fault (*see* p. 60), in which are found several repetitions of the Marsh-Adams, Mohican, Badshot, and Lower Index Formations. The repetitions are caused mainly by Phase I folds. Stratigraphic evidence indicates that the belt contains two isoclinal synclines with rocks of the Index Formation in each trough, separated by an isoclinal anticline of Marsh-Adams Quartzite. In addition there are a number of subsidiary infolds of the Mohican and Badshot Formations. Throughout the belt the layers are essentially parallel, and south of Hamill Creek form an apparently homoclinal succession dipping 60 to 65 degrees to the west. Although some of the layers, particularly the limestones, pinch out down the dip, no Phase I folds are seen and no hinge zones have been recognized. Most layers are remarkably continuous, and any lenticularity appears to result from shearing or flowage parallel to the layers. North of Hamill Creek the layers are folded, and steepen in dip and swing in strike toward the northwest. This folding is the result of Phase II or later deformation.

Meadow Creek Anticline

The Meadow Creek anticline is a complex, broadly folded anticline named from exposures on both sides of the valley of lower Meadow Creek. Characteristics of the anticline are shown most clearly in rocks of the Marsh-Adams, Badshot, and Lower Index Formations in the Lardeau Bluff, on both sides of the Duncan Valley, and on the bluffs northwest of Marblehead. The fold is very complex in detail, and large parts of it are not exposed. The cross-sectional form must be interpreted from widely spaced exposures. It is an isoclinal fold with complex digitations which, in the lower formations, are mainly synclines within Marsh-Adams Quartzite of Badshot and locally the lowest part of the Index Formation. The Meadow Creek anticline coincides with the Kootenay Lake antiform, and consequently the anticline is broadly recumbent. The axial plane dips at a low angle to the west on the west side of Kootenay Lake and the Duncan Valley; it flattens on the bluffs northwest of Marblehead and dips to the east at moderate angles on the east side of the Duncan Valley. The axial zone is exposed along the Lardeau Bluff and in the canyon and bluffs south of Davis Creek. It contains a number of digitations related to the main anticline which are complexly folded by Phase II structures (*see* p. 51). Deformation has caused many of the key formations, noticeably the Badshot Limestone, to be lenticular. Some lenses are digitations which have been pinched off by folding (*see* Fig. 12); others are along the limbs of folds. Complexities of the outcrop pattern in an oblique section exposed on the Lardeau Bluff are shown in Plate XIX. The anticline is thought to open downward to the east, but the outline is complicated by the fact that the thickest sections of the Marsh-Adams Quartzite in the core of the fold are also in the crestal zone of the Kootenay Lake antiform. This relationship is emphasized in the diagrammatic section, Figure 16.

The Meadow Creek anticline has not been recognized in rocks of the Index Formation west of Meadow Creek, on Lardeau Ridge, and along the east side of the Lardeau River. The contact shown on Figure 3 as the top of the Lower Index is on the upper, right-side-up limb of the Meadow Creek anticline. Rocks lying spatially above it, to the north and east, are probably contained in a major Phase I syncline called the St. Patrick syncline.

St. Patrick Syncline

This syncline is poorly defined because it is mainly in rocks of the Index Formation in which the stratigraphic succession is not known with certainty. The name of the syncline is taken from the St. Patrick mine north of Hamill Creek, where a more or less symmetrical repetition of the formations provides the strongest evidence for the presence of the fold. The Badshot and Lower Index Formations east and west of the mine are on the limbs of the fold, and the Upper Index is in the trough. The axial plane, defined by the formational dip, dips to the east at moderate angles, and the axis probably plunges to the north. The Argenta fault truncates the syncline on the southeast, and several strike faults lie along the contact of the Lower and Upper Index on the western limb of the syncline.

FAULTS

The dominant faults in the map-area are more or less parallel to the formational strike and are vertical or dip steeply. Some of the faults are clearly related to Phase II foliation planes, but for most it is possible to conclude only that they truncate Phase II structures.

Faults resulting from slip on Phase II foliation planes are displayed best on the southwest slope of Comb Mountain, on the western limb of the Comb Mountain antiform. They strike between 5 and 15 degrees west of north and dip 45 to 65 degrees west. Many small faults and several larger ones can be seen in which marker beds have moved up on the west in relation to those on the east—they are reverse faults. The largest apparent dip-slip on any of the faults is no more than 500 feet, and the strike-slip is thought to be relatively insignificant, although there is no direct evidence for this conclusion. Faults with a dip-slip of a few inches, observed in many outcrops of quartzite, are parallel to the cleavage and are obviously cleavage planes on which there is visible displacement. The relative movement may be reversed or normal, but on the west limb of the antiform it is most commonly reversed.

A strike fault dipping to the west separates the Comb Mountain antiform from the Glacier Creek synform, between Hamill Creek and the southern edge of the map-area. The fault is along the western side of the Mohican Formation, causing the formation to be thinned and to pinch out entirely south of Clint Creek. The relative movement on the fault is not known. A strong fault on the eastern limb of the Glacier Creek synform, which may be the northern extension of the fault just described, is found on both sides of Glacier Creek, and on the north side of the creek is less than half a mile west of the Surprise mine. It is marked by a strongly contorted and crushed zone several feet wide with a vertical dip and a strike of north 10 degrees west, and is parallel to a strong schistosity which is a second foliation. Rusty pyrite in this fault zone has been tested by a short adit at an elevation of 3,500 feet north of Glacier Creek and by trenching at a number of places south of the creek.

A fault, named the Argenta fault, causes a major discontinuity of structures west of the Duncan anticline. It crosses Hamill Creek near the mouth of Clint Creek and has been followed northward to the Duncan Valley south of Glacier Creek and southward to a covered area near Argenta. The strike is north 10 degrees west and the dip is steep to the west. Where exposed on the north side of Hamill Creek, it is a zone of shearing several feet wide on the east side of a belt of highly contorted schist and limestone several hundred feet wide. In this belt, Phase II structures appear to be warped and disrupted. To the east, the rocks are parallel to the fault zone and, though sheared, are not abnormally disturbed. Where the fault zone is exposed near the Lavina trail south of Glacier Creek, it contains black schists with large lenses of white limestone on the west and sheared micaceous quartzites of the Marsh-Adams Formation on the east. South of Hamill Creek the fault appears to split; one branch is along the valley containing the Hamill Creek trail, and the other is on the eastern side of a small valley to the west. South of Argenta, a fault which is probably the Argenta fault is recognized between Argenta and Bulmer Creeks. Although the fault is not exposed, the trace of the disturbed zone indicates a northerly strike and a moderate westerly dip. This zone separates westerly dipping grey schists and limestones on the east from similar easterly dipping rocks to the west. The rocks to the east are not abnormally disturbed, but those to the west become progressively more contorted toward the fault zone. In general it appears that movement on the Argenta fault, the amount and direction of which is unknown, has taken place parallel to foliation on the footwall side of the fault and has transected and disturbed the layers on the hangingwall side.

The fault almost certainly continues northwest of the Duncan Valley, and although its location is uncertain, it is thought to lie parallel to the foliation, along the northeastern side of the extensive volcanic member of the Index Formation on the eastern side of the Lardeau River.

A fault which shows as a prominent lineament on air photographs extends northward along Lardeau Ridge 2 to 3 miles north of Marblehead. The fault strikes north 30 degrees west, dips steeply to the northeast, and has offset the formations on the eastern limb of the Kootenay Lake antiform. The fault is clearly marked though it is not exposed in bluffs north of Marblehead, and drag in rocks near the fault suggests that the displacement is dominantly parallel to the dip. The top of the Badshot Formation has been dropped down on the east about 500 feet by the fault. The fault probably continues southeast of the Lardeau and Duncan Valleys. On the south bank of the Duncan River two pronounced shear zones are exposed in grey and green schists of the Index Formation just east of the road to the St. Patrick mine. They are parallel to the schistosity of the enclosing rocks and probably continue at least as far south as Hamill Creek. They probably are the southern continuation of the fault north of Marblehead.

Along the valley of Meadow Creek and extending northward toward Goldhill is a lineament which shows prominently on air photographs. It transects at a small angle a prominent structural grain of the country. The lineament probably is the surface trace of a steeply dipping fault, but there is little evidence of offset where the lineament crosses the Badshot Limestone about 4 miles northwest of Marblehead. Although outcrops are not abundant enough to define all the contacts, and the low formational dip causes a complicated outcrop pattern, the offset along the lineament is no more than a few hundred feet and the dip-slip is less than 200 feet.

STRUCTURAL PATTERNS AND SEQUENCES

Structural studies in the Duncan Lake area have reached a stage at which the forms of folds, and the fold patterns and spatial relationships between folds are fairly well known. The foregoing pages of this chapter have been concerned largely with details of the geometric aspects of the structure. Figure 16 shows the general structure of the area in one cross-sectional diagram. It has been prepared by projecting known folds relatively great distances along the plunge, a technique made possible by the uniform plunge of the folds and aided by the averaging and analysing of field measurements on stereonets. The geometry of the structures is fairly well known, but very little is known of the structural history and the deformative processes. The following paragraphs discuss briefly some aspects of the history and of the processes.

Phase I folds are the oldest structures recognized. Still older structures may have been obscured or obliterated by the subsequent deformation, but such structures, if they remain, appear to be unimportant in controlling the distribution of the rocks and configuration of later structures. Direct evidence of a time lapse between the formation of Phase I and Phase II structures has not been found, and the parallelism of Phase I and Phase II fold axes is taken as evidence that the two are closely related parts of one protracted deformation. Among the more obvious events in the history of the area, to be related to the Phase I and Phase II structures, are the regional metamorphism, the emplacement of felsite and lamprophyre sills and dykes, and the development of the late folds. The development of the dolomite, siliceous dolomite, and sulphide zones is discussed in Chapter IV.

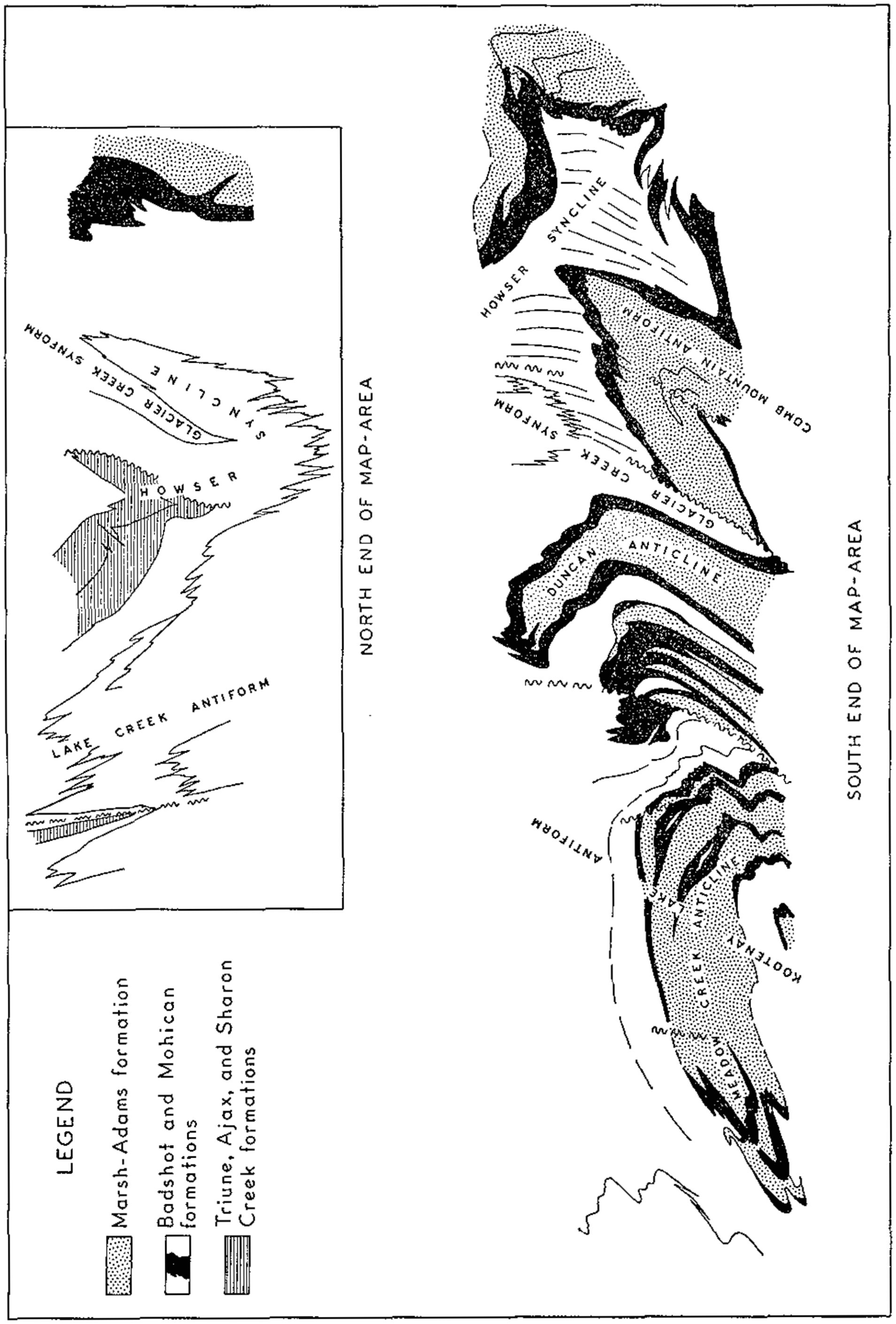

Figure 16. Idealized composite cross-sections showing the structure of the Duncan Lake area.

Deformation continued during metamorphism, as is indicated by bent mica flakes and rolled garnets seen commonly in thin-sections. Where the relationships are clearest, the mica flakes appear to have been bent by Phase II structures, and it is probable that metamorphism had reached a relatively high grade late in the first phase or early in the second phase of deformation. Thin-section evidence also suggests that in the southern part of the area metamorphism may have continued at a relatively high grade through the second phase of deformation, because deformed quartz grains and micas seen commonly in the northern part of the area are rarely seen in the south and appear to have been obliterated by recrystallization.

The felsite sills are thought to have been intruded before Phase II deformation was complete because they have a poor lineation parallel to Phase II lineations and locally they follow Phase II folds. Swarms of sills with narrow but continuous partings of wallrock between them indicate that emplacement was by a passive process, under conditions of relative extension perpendicular to the first foliation. Thin-sections of the felsites show very little evidence of deformation, and the composition and texture do not vary with metamorphic grade. Possibly the felsites were intruded at a very late stage in the second phase of deformation.

Little is known of the origin and significance of the late folds, except that they are superimposed on the two older phases of folding. Locally they dominate the fold structure, and regionally some or all of the late folds may be related to the regional swing in the structural trends. The lamprophyre dykes show no evidence of having been deformed and were probably intruded after the late folding was complete.

Phase II folds vary greatly in form and include concentric types in the most competent rocks, more or less attenuated similar folds with rounded or sharp crests, and locally sharp-crested chevron folds. Concentric folds are uncommon, although some small folds in quartzites are concentric and parts of some major Phase II folds may approximate concentric form. The majority of Phase II folds on all scales are of the similar type and have developed in part by bending of the first foliation layers and in part by slip on the planes of second foliation cleavage and schistosity. Lithology is an important controlling factor in the form of the folds. In the more or less uniform schists of the Index Formation, bedding appears to have had a passive role in folding, and movement on schistosity planes has, in extreme cases, developed almost isoclinal Phase II folds in which the limbs are virtually parallel to the schistosity. Locally, particularly in complexly interlayered quartzites and mica schists, a strong first-phase schistosity has been bent in Phase II folding to produce chevron folds with fairly straight limbs and sharp crests. More commonly in quartzite-schist sequences, folding has taken place by both flexing of the layers and slip on the cleavage planes.

In most of the area the schistosity and (or) cleavage and the axial planes of Phase II folds dip steeply. In the crestal zone and western part of the Kootenay Lake antiform the visible Phase II folds have axial planes that are recumbent and are curved with the formations. The asymmetry of the folds suggests an overriding of the upper layers west over the lower ones on planes more or less parallel to the formations.

Patterns of both Phase I and Phase II folds are consistent enough throughout the area to suggest that the major folds developed in response to more or less homogeneous stress systems applied to an area larger than the map-area. Local stresses have produced local variations in the structures, but these do not obscure the regional pattern. Little is known of the pattern of major Phase I folds before the Phase II deformation, but the distribution of the formations over an area larger than the Duncan Lake area, in which progressively younger rocks lie to the west and older ones to the east, may be interpreted to mean that the Phase I folds rose step-like toward the Purcell anticlinorium on the east. Major Phase II folds ideally consist of an antiform lying east of a synform. They have the shape of a reversed N and may be regarded as sinistral dragfolds suggesting movement of the east up in relation to the west. In most of the Duncan Lake area this movement was on moderate to steep planes striking northward and dipping to the west in the southern part of the area, and to the east in the northern part. In the southwestern part of the area, movement may have been taken up by flowage around the crest of the Kootenay Lake antiform.

Patterns of folding within the Duncan Lake area are found also in other parts of the Kootenay arc, and it is expected that in the course of future studies in the arc, structures will be recognized that can be correlated with those in the Duncan Lake area. " Primary " and " secondary " structures as well as local " late cross-folds " were found in the Salmo area (*see* Fyles and Hewlett, 1959, p. 47) which may be correlated directly with the Phase I, Phase II, and late structures of the Duncan Lake area. Two phases of deformation correlated with those at Duncan Lake have been found in the Kaslo-Ainsworth area in a study not yet completed. Only one major phase of folding was recognized in the Ferguson area, and it has been correlated with the first phase of folding of the Duncan Lake area (*see* Fyles, 1962, p. 22), but it is possible that both Phase I and Phase II folds, although not detected in the original work, are also present in the Ferguson area.

CHAPTER IV.—MINERAL DEPOSITS

INTRODUCTION

The most important mineral deposits in the Duncan Lake area are relatively low-grade zones of lead-zinc mineralization that have been extensively explored recently but have not yet been mined. They are referred to as the Duncan type of deposit, from the Duncan mine on the peninsula on the east side of the lake. Although details of the mineralization and the exact forms of the mineralized zones will not be known until mining takes place, the present geological studies and prospecting and exploration, mainly by The Consolidated Mining and Smelting Company of Canada, Limited, have shown the geological setting and general form of the zones.

The only production from mines within the map-area has been from a number of silver-bearing lead-zinc deposits of various types. This production is summarized in the following table. The column headed " Year " gives the main periods of production. In this chapter the general characteristics of the Duncan type of deposit are discussed, and descriptions of all the known properties are given. A summary of the history of mining and exploration in the map-area has been included in Chapter I.

PRODUCTION FROM MINES WITHIN THE DUNCAN LAKE AREA

Name	Year	Tons	Gold (Oz.)	Silver (Oz.)	Copper (Lb.)	Lead (Lb.)	Zinc (Lb.)
Argenta	1900	45	....	4,017	......	7,972	......
Surprise	1923–26 1946–54	1,318	18	41,561	2,138	20,852	21,534
Lavina	1901–02 1918 1927	232	....	8,678	......	269,508	......
Moonshine-Right Bower	1951–53 1957	463	1	5,601	964	176,655	196,140
St. Patrick	1919 1927 1937–38	42	....	1,227	......	30,792	14,789
Totals	......	2,100	19	61,084	3,102	505,779	232,463

LEAD-ZINC DEPOSITS OF THE DUNCAN TYPE

Essentially all the lead-zinc deposits of the Duncan type are in the Badshot Formation on the Duncan anticline. They include mineralized zones on the Duncan property which extend from the peninsula in Duncan Lake to Glacier Creek, the Lavina property near Lavina Lookout, and the Sal property on Mount Willet (*see* Plate VI) and south of it. These zones are on the eastern limb of the anticline. Mineralized zones on the Mag and Argenta properties west of Lavina Lookout are on the western limb of the Duncan anticline. Scattered occurrences of lead-zinc mineralization are known in the Badshot Formation between these properties. In all, between 15 and 20 mineralized zones are known on the Duncan anticline within the map-area.

Most of the showings were discovered many years ago, and some work was done on them in the early days. Small amounts of ore were shipped from the Argenta and Lavina properties in 1900 and for a few years thereafter. The showings on Glacier Creek and Duncan Lake were known before 1920 and, although there are no published records, old workings on the other properties are evidence of their early discovery. Because of the disseminated character of the sulphides and the general low silver content of the zones, they have been of little economic interest until recently. Since about 1950, exploration of the deposits near Duncan Lake has outlined relatively large tonnages of low-grade ore. This exploration was done by a number of companies, the most successful of which has been The Consolidated Mining and Smelting Company of Canada, Limited, which now owns the Duncan and several properties to the south.

The mineralized zones on the Duncan property are exposed on surface in a number of trenches and underground in the Duncan mine, and in what is known as the Lardeau Lead and Zinc Company adit on the north side of Glacier Creek. All the zones on the property have been drilled from surface, and those near the Duncan mine have been drilled extensively both from surface and underground. Mineralized zones on the other properties are known mainly from natural exposures and some trenching, drilling, and old underground workings.

The purpose of this study and of the following descriptions is to give the structural setting and general features of the Duncan type of deposit. The writer has relied on the property mapping (mainly on scales of 100 feet to the inch) and core logging of geologists of the Consolidated company for many of the details of the deposits, particularly those at the Duncan mine. Most of the maps have been checked in the field, and some of the core has been relogged by the writer. Detailed descriptions of the mineralized zones on the Duncan property given by Muraro (1962, Chapters 4 and 5) have been used in preparing this report.

CHARACTERISTICS OF THE MINERALIZED ZONES

Mineralized zones of the Duncan type consist of pyrite, sphalerite, galena, and minor pyrrhotite disseminated in dolomite and siliceous dolomite of the Badshot Formation. They are lenticular zones with gradational but in general well-defined margins. The attitude of the zones is essentially parallel to that of the enclosing formations, and consequently the strike is about north 20 degrees west and the dip in general is steeply to the east north of Hamill Creek and to the west south of Hamill Creek. The largest dimension is parallel to the strike, and the intermediate dimension is parallel to the dip. These dimensions vary widely and have not been fully determined for any of the zones. The longest zone found so far is more than 3,000 feet long. The height measured more or less parallel to the dip may be as great as 500 feet, and the thickness is generally a few tens of feet but may be as much as 100 feet; the margins are irregular and gradational. Close drilling at the Duncan mine has shown that the longest axes of the mineralized zones plunge at a low angle to the north—an average plunge of 7 degrees at north 20 degrees west. This plunge is parallel to the most prominent lineation and to the axes of Phase II folds in the surrounding rocks. Although the zones south of the Duncan mine are not as well known as those at the mine, they also appear to plunge at low angles to the north and probably have the same plunge as nearby Phase II folds.

The mineralized zones are in dolomite and siliceous dolomite of the Badshot Formation. The general lithological succession of the Badshot on the Duncan anticline is given in Chapter II (*see* p. 25). It consists of a lower and an upper dolomite separated by a thin layer of crystalline limestone. The uppermost part of the upper dolomite is siliceous. Mineralized zones are found in both the lower and the upper dolomites and along the contact between the upper dolomite and the siliceous dolomite. The terms " upper " and " lower " are used in a stratigraphic sense, so that where the formation is overturned as on the Sal and Mag properties, the lower dolomite is spatially above the upper dolomite. On the Duncan property, one important zone and some scattered mineralization are found in the lower dolomite, and the remainder of the mineralized zones are in the upper dolomite, particularly along the contact between the dolomite and the siliceous dolomite. South of the Duncan property the mineralized zones are within the dolomite members and locally along dolomite-limestone contacts.

The proportion of individual sulphides in the deposits varies widely. In general, pyrite is the most abundant sulphide, and sphalerite is more abundant than galena. Pyrrhotite in minor amounts is present in one zone in the Duncan mine, and minute amounts of chalcopyrite, marcasite, ruby silver, and meneghinite are reported by Muraro (1962, p. 77). The sulphides in general are very fine grained. They form disseminated grains, lenticular clusters, or fairly massive layers in dolomite. Layers with disseminated grains are commonly in thin bands of white limestone that on weathered surfaces form depressed layers in the dolomite. Individual layers follow the foliation of the dolomite fairly closely and locally display folds with irregular cross-sectional form, rounded hinges, and axes which plunge parallel to the axes of the mineralized zones.

The grade varies widely, and an average grade of a mineralized zone can be determined only by extensive systematic sampling. Most samples of representative mineralization taken by the writer contain about 2 per cent lead, about 6 per cent zinc, and traces of gold and silver over widths ranging from 2 to 40 feet. One sample assayed 8.75 per cent lead and 6.1 per cent zinc across a width of 16 feet.

DOLOMITE

Because of the close association of the mineralized zones with dolomite, the distribution and general characteristics of the dolomite are significant in exploration. The term " dolomite " refers to the mineral $(CaMg)CO_3$ and also in this report to the rock composed of more than 80 per cent of that mineral. The term " limestone " refers to a rock composed of more than 80 per cent calcite. These definitions of dolomite and limestone, introduced by Green (1954) from studies in the Salmo Camp, are particularly useful because rocks that are normally distinguishable as dolomite in the field, on further testing, are found to contain more than 80 per cent $(CaMg)CO_3$ and hence readily fit the classification. In general, dolomite can be easily distinguished from limestone in the field by its weathering characteristics, colour, and grain size. Dolomite is commonly closely fractured, and although fractured blocks are rounded, they are more angular than similar blocks of limestone. Fresh surfaces are some shade of grey, and weathered surfaces vary from grey with a slight tinge of buff or cream colour to buff and locally brown. Dolomite in general is finer grained than limestone, but the grain size varies widely, and the two rock types cannot always be distinguished on this basis alone. A drop of dilute hydrochloric acid, which does not effervesce on dolomite and does effervesce on limestone, provides a test that is quick, but one that may be misleading if a few grains of calcite or powdered dolomite are present. Partial chemical analyses reported by Muraro (1962, p. 38) of 13 samples of dolomite from the Badshot Formation on the Duncan property all contain more than 80 per cent dolomite. Of six analyses of samples from dolomite members in the Mohican Formation in the same locality, only one contained less than 80 per cent dolomite.

In general in the Duncan Lake area, dolomite is found almost entirely in the Mohican and Badshot Formations, and the distribution within these formations is shown on Figure 6. The thickest and most continuous layers of dolomite are in the Badshot Formation of the Duncan anticline, and from careful studies by geologists of the Consolidated company it has been concluded that the dolomite is confined to two horizons—the lower dolomite and the upper and adjacent siliceous dolomite. Only lenses of dolomite are found in the Badshot away from the Duncan anticline, and they cannot be correlated with the dolomite members on the anticline. Dolomite in the Mohican Formation on the Duncan anticline is found only on the eastern limb north of Lavina Lookout. Essentially all the dolomite east of the Duncan anticline is in the Mohican Formation, and no significant occurrences of lead and zinc are known in the Mohican dolomite.

Two intergrading types of dolomite are known in the Duncan Lake area—one massive, the other textured. Textured dolomite contains black or dark-grey flecks, streaks, or bands outlined by concentrations of carbon. The streaks and bands are a fraction of an inch thick, and although they are discontinuous in detail, they give the rock a fairly well-developed foliation generally parallel to the formational boundaries. Terminations of the streaks give a more or less well-developed lineation, in general parallel to the most prominent lineation in the enclosing rocks. Streaked and banded dolomites grade into those with mottled and flecked textures which have a fairly good lineation and a poorly developed foliation. Massive dolomite is most commonly light grey and weathers cream coloured, buff, or brown. Locally on fresh surfaces it is cream coloured or white, and elsewhere it is medium grey. In the Duncan anticline much of the Badshot dolomite and some of the Mohican dolomite is textured. Away from the Duncan anticline most of the dolomite is massive, though some lenses in both the Badshot and Mohican are textured. Dolomite associated with the mineralized zones in general is textured.

Siliceous dolomite found in the Badshot Formation in the Duncan anticline is a fine-grained dark-grey banded or mottled rock ranging from dolomite with scattered grains of disseminated quartz to a rock with a cherty appearance containing only small lenses of dolomite. Thin-sections show that the siliceous dolomite is composed of very fine-grained carbonate and quartz with minor amounts of carbon which, in part, give the greyish colour. The quartz and carbonate have either a mosaic texture or a texture in which the quartz grains appear sheared and have a strong dimensional orientation. In outcrops the foliation is strongest where the proportion of quartz is low, but lineation is prominent in almost all of the siliceous dolomites. The lineation is accentuated locally by rods of dolomite or siliceous rock an inch or more in diameter which themselves have minutely crinkled carbonaceous layers on their sides. Some siliceous rods are lenticular in cross-section and have a dolomitic core (*see* Plate XXI). The siliceous dolomite is almost entirely in the upper part of the upper dolomite but is found locally in the lower. Though fairly continuous in the upper dolomite, it lenses out in places, such as on the north slope of Hamill Creek and on the Sal property, into grey dolomite. On the western limb of the Duncan anticline, siliceous dolomite is found only in discontinuous lenses grading along strike into dolomite or limestone.

Some siliceous rocks are present in the Badshot and adjacent formations away from the Duncan anticline. West of the anticline they form a number of lenses, mainly south of Hamill Creek. The largest extends half a mile north from Bulmer Creek near Kootenay Lake and is a banded or mottled white and dark-grey cherty rock in the Badshot and lowermost part of the Index Formation. Somewhat finer-grained grey siliceous limestones are found near the Argenta fault north of Argenta. In the eastern belt on Lavina Ridge the upper part of the Badshot Formation contains siliceous limestone. The siliceous layers are dark grey, as much as 3 inches thick, and in thin-section are composed of very fine-grained quartz and calcite texturally similar to the siliceous layers in the dolomite on the Duncan anticline. Siliceous limestone like that on Lavina Ridge is present also in the Badshot north of Duncan Lake. The known occurrences of siliceous dolomite and limestone are shown on Figure 6.

The origin of the dolomite and the siliceous rocks is uncertain. Deformation and regional metamorphism have complicated the stratigraphic relationships and obscured the evidence for processes which may have taken place during or soon after sedimentation or in the early stages of deformation.

Both the dolomite and the siliceous dolomite have been deformed and are clearly older than the Phase II folds. Deformation of the dolomite is indicated by mottled and flecked textures and by folded dolomite-limestone contacts. Most banding in the dolomite is a first foliation, and is probably bedding modified by deformative movements. Mottled and flecked textures result from the modification of the first foliation, at least in part, by the second foliation, and by Phase II folds. In the siliceous dolomite, prominent rodding, sheared and contorted layers and lenses, and textures seen in drill cores and thin-sections all indicate that the dolomite was siliceous before deformation. The most continuous layers and the intermediate axes of siliceous lenses are parallel to the first foliation; the longest axes of the lenses are parallel to the Phase II lineation. The shapes of the siliceous lenses in some exposures (*see* Plate XXI) suggest that they are chert nodules modified by deformation. Whether they formed in the early stages of folding as epigenetic replacements or by diagenesis is not known. There has been considerable solution and redeposition of silica during deformation. Lenses and veinlets of vein quartz both parallel to and transecting the foliations are common. A large white quartz vein follows the upper contact of the Badshot Formation on the western limb of the Duncan anticline south of Mount Willet in a region where there is no siliceous dolomite. These lenses and veins of quartz clearly formed late in the history of deformation, but it is probable that there was also a migration of silica-bearing solutions earlier in the deformation that contributed to the pronounced rodding.

LEAD-ZINC MINERALIZATION

No evidence has been found for the source of the lead-zinc mineralization, but recent studies of lead isotopes in the Kootenay arc (Sinclair, 1963) show that the deposits are epigenetic. Field observations indicate that the present form and distribution of the Duncan type of deposit are both controlled by the structure, and strongly suggest that dolomite has been replaced in favourable structural situations. Probably the most significant structural feature affecting sulphide migration and deposition has been the way in which the Badshot Formation on the Duncan anticline has responded to deformation, particularly to the Phase II deformation. In rocks below the Badshot, regular Phase II folds have commonly developed, in part by interbed slippage and in part by shearing parallel to the cleavage planes (*see* p. 44). Only a very few folds of this form are present in the Badshot however. Two such folds are outlined by dolomite and limestone near the road in the canyon of Glacier Creek and a few irregular folds occur in the same rocks well above the road. Mostly the first foliation banding and layering within the Badshot is not folded but is sheared or brecciated, giving mottled and streaky textures. The small folds that are recognized are disrupted and irregular in cross-sectional form but are uniform in plunge. Foliation in the Index adjacent to the Badshot is a schistosity or cleavage parallel to the first foliation. Higher in the Index, Phase II cleavage transecting first foliation becomes dominant. No regular infolds of the Index in the Badshot like those in the underlying Mohican are known. These relationships, sketched in Figure 8, suggest that the Badshot Formation has responded to deformation by flowage, brecciation, and shearing more or less parallel to the formational boundaries, in contrast to the regular pattern of folding in the overlying and underlying formations. The physical properties of the carbonate rocks controlled their deformation, and the pattern of deformation probably controlled the migration and precipitation of sulphide minerals.

The textures and structures in zones of lead-zinc mineralization seen in outcrops and the walls of mine workings are clearly the result of replacement. Incompletely replaced layers, rounded corroded dolomite fragments, and relict fold structures are common. Pyrite seen in polished sections under the microscope is shattered and is intimately intergrown with sphalerite and galena which were deposited after the pyrite. Some polished surfaces of sulphides show a poor microfoliation that is either inherited or has been impressed on the sulphides by deformation. Though shattered, the pyrite crystals appear to have been recrystallized and occur as clusters of aggregates. It is concluded that the pyrite and probably the other sulphides have been deformed and subsequently recrystallized.

On a regional scale, lead-zinc mineralization is clearly localized along the Duncan anticline. Coincident with this anticline are relatively thick and continuous dolomite and siliceous dolomite layers in the Badshot Formation, the structural significance of which has already been discussed. Dolomite and siliceous dolomite are found in other places (*see* Fig. 6) and are locally mineralized, but the major structure, with continuous, structurally favourable carbonate layers, was of prime importance in causing widespread mineralization.

Muraro (1962) has drawn attention to the close similarity in mineralogy, texture, and mineral zoning between the Duncan deposits and those of the upper Mississippi Valley (*see* Heyl *et al.*, 1959, and Ohle, 1959) and has concluded that because of this similarity the Duncan " deposit formed in relatively flat-lying sediments before folding." This conclusion, however, neglects the Duncan anticline and the obvious control of mineralization by the presently known structures. A better explanation of the similarities between the deposits is that processes active in the development of the Mississippi Valley deposits were also important in the formation of the Duncan deposits, but the migration and deposition of the Duncan sulphides were controlled by the anticline and subsidiary structures and not by older structures in relatively flat-lying sediments.

DESCRIPTIONS OF PROPERTIES

Argenta

The Argenta property, on the north side of Hamill Creek about 1 mile south of Lavina Lookout, consists of three Crown-granted claims owned by J. C. Hansen, of Salmo. The property is an old one on which considerable work was done between 1900 and 1910 and on which little or no work has been done since. More than 1,000 feet of underground workings are described in old reports. Showings on the property examined by the writer consist of scattered occurrences of lead-zinc mineralization in dolomite and siliceous dolomite of the Badshot Formation on the western limb of the Duncan anticline. They are exposed in old pits and trenches, reached by following an old trail which leaves the Hamill Creek trail at the old compressor about 1 mile above the mouth of Clint Creek, and climbs the north slope of Hamill Creek to elevations of 3,500 and 4,000 feet. The dolomite dips to the west at about 45 degrees, and lenses of finely disseminated pyrite, sphalerite, and galena occur with grey and white quartz. Outcrops are scattered near the showings, and it is uncertain which member of the Badshot the mineralized zone is in. A zone 75 to 100 feet long and up to 3 feet thick is exposed in several trenches at an elevation of about 3,600 feet. Another short mineralized zone in siliceous dolomite is at an elevation of 3,000 feet and is exposed in one old trench.

The showings on the property are described as follows by R. W. Brock (1908), who visited them in 1907:—

" There are two veins on the property of this company, the Clinton vein which strikes N. 10° W., with a dip of 55° west, and the Mabel-Nora vein striking about N. 8° W., 450 to 500 feet east of the Clinton vein.

" The Clinton is a quartz vein carrying chalcopyrite, some gold, and silver to the extent of about one ounce of silver to each per cent of copper present in the ore. The vein occurs in a fissured zone about ten to twenty-five feet in width, with a well marked slickensided hangingwall. The shattered material of this zone forms the ledge material, in which the ore, generally about one foot in width, though widening to two and a half feet, is developed, more frequently probably along the foot wall of the fissured zone. The Mabel-Nora vein is a silver lead vein. The country rocks are limestone phyllites and chlorite schist. Most of the work has been done on the Clinton vein."

The showings described in the present report are probably on the Mabel-Nora vein. The Clinton vein and most of the workings which were not found by the writer are probably in dark grey-black slaty rocks of the Lower Index Formation west of a steep ravine.

[References: Brock, 1908, pp. 88–89; *Minister of Mines, B.C.,* Ann. Rept., 1904, p. 162.]

Duncan

The Duncan property consists of about 60 recorded claims owned by The Consolidated Mining and Smelting Company of Canada, Limited, extending from the peninsula on the east side of Duncan Lake to Glacier Creek. They cover the Badshot and Mohican Formations on the eastern limb of the Duncan anticline and include a number of old properties, notably the Lakeside on the peninsula, the Amato and Ruby on the slope east of Duncan Lake, and the Glacier property on the northwest side of Glacier Creek. These properties were located about 1925, although the lead-zinc mineralization on them had been known for many years before. The showings near Glacier Creek were drilled by the Consolidated company in 1927, and after this company dropped them were located by Joe Gallo and associates, of Howser, as the J.G. group. In 1952 the southern part of the property was drilled by Lardeau Lead & Zinc Mines Ltd., and an adit at an elevation of about 2,550 feet was driven. Exploration was continued by Berens River Mines Limited and in 1955 and 1956 by The Bunker Hill Company of Kellogg, Idaho, who did diamond drilling and trenching, mainly on the peninsula. In 1957 the property was optioned from Mr. Gallo and associates by The Consolidated Mining and Smelting Company of Canada, Limited. Geological mapping and diamond drilling were followed in 1959 and 1960 by underground exploration in the Duncan mine on the peninsula (*see* Fig. 3). Several million tons of low-grade lead-zinc mineralization is indicated, and it is expected that under more favourable conditions the zones will be mined.

Eight mineralized zones have been found on the Duncan property.

No. 1 zone, on the north side of Glacier Creek, is exposed in the adit of Lardeau Lead & Zinc Mines Ltd. and in trenches nearby.

No. 2 zone is on the crest and western side of the ridge between Glacier Creek and Duncan Lake at an elevation of about 3,500 feet.

No. 3 zone is on the south side of the entrance to the Lower Arm of Duncan Lake.

No. 4 zone is on the peninsula on the north side of the entrance to the Lower Arm.

No. 5, No. 6, No. 7, and No. 8 zones are in the vicinity of the Duncan mine.

No. 3, No. 4, and No. 5 zones are known mainly from drilling.

No. 6, No. 7, and No. 8 zones have been drilled and are exposed in the mine.

Rocks on the Duncan property belong mainly to the Mohican and Badshot Formations but include also the upper part of the Marsh-Adams and lowermost rocks of the Index. These formations in the Duncan anticline are described in Chapter II. The Marsh-Adams is a succession of grey to brown micaceous quartzites with minor mica schist and platy white quartzite. It is overlain by the Mohican Formation of interlayered carbonates, mica schist, and very fine-grained micaceous quartzite in a stratigraphic sequence given on page 22. Near Glacier Creek much of the carbonate is limestone, whereas to the north it is dolomite. The Badshot is a succession of limestone and dolomite with siliceous dolomite at the top, as outlined on page 24 and described again in the preceding general discussion of the Duncan type of lead-zinc deposit. The lowermost part of the Index Formation which overlies the Badshot is dark-grey to black siliceous argillite and fine-grained mica schist.

These formations on the Duncan property are on the eastern limb of the Duncan anticline, a major Phase I isoclinal fold (*see* p. 58). The Mohican Formation, as repeated on the western limb of the anticline, is exposed at the base of the slope on the east side of the Duncan Valley just north of Glacier Creek and passes beneath the valley fill to the north. The hinge line of the Duncan anticline, at the top of the Marsh-Adams Formation, is probably just west of the property, but has not been recognized either east of Duncan Lake or on the peninsula.

Virtually all the structures seen on the property are Phase II folds. These are relatively tight asymmetric or overturned folds, well displayed in the Mohican Formation on the north side of Glacier Creek, at the south end of the peninsula, and in crosscuts of the Duncan mine (*see* Fig. 17). Most of the folds are a few feet across, but some are larger. On the peninsula an anticline with Marsh-Adams Quartzite in the core lies east of a shallow syncline with Mohican Formation in the trough, which is well exposed at the south end of the peninsula (*see* Fig. 3). The anticline, somewhat modified by steep westerly dipping strike faults, probably passes just west of the portal of the Duncan mine. It is not the Duncan anticline, but a Phase II fold on the eastern limb of the Duncan anticline. In cross-section the exposed folds have steeply dipping axial planes and have the shape of a reversed N, rising more or less step-like to the west. The axial planes, defined by a well-marked cleavage in micaceous rocks of the Mohican Formation, dip steeply to the east near Glacier Creek and steeply to the west on the peninsula. The axes of the folds plunge north 20 degrees west at 5 to 10 degrees. The folds are important in determining the average dip of the formations and in controlling at least part of the mineralization.

Two important westerly dipping strike faults and several smaller ones are recognized in the Duncan mine. Probably others are present on the property but have not been found even by close mapping. The faults exposed in the mine strike north 20 degrees west and dip steeply to the west. The apparent dip-slip is a few hundred feet down on the west. From observations along the fault planes in the mine and in drill core, Muraro concludes that movement has taken place since the formation of the siliceous dolomite and the sulphides, and also that the faulting is closely associated with the folding.

Figure 17 is a cross-section along the main or 1854 crosscut of the mine, taken from a drawing of the Consolidated company. It shows the pattern of folding and faulting and the distribution of three of the mineralized zones. Careful studies of the lithological succession by company geologists have made it possible to reconstruct drill sections with a minimum of inference. The folds are Phase II structures, and the patterns determined by company geologists are the same as those found in the present regional study.

The general features of the mineralized zones have been described earlier in this chapter. Details of the mineralization given here are taken largely from descriptions given by Muraro (1962, Chapter V). The Duncan mine, at an elevation of

1,840 feet, is roughly 40 feet above Duncan Lake and consists of a crosscut (the 1854 crosscut) about 1,000 feet long driven north 70 degrees east through the mineralized zones and a drift driven southward for about 3,000 feet along No. 7 zone. Three crosscuts run westward from the drift, and a short drift and raise to surface have been made north of the main crosscut. The mineralized zones have been outlined by diamond-drill holes drilled on vertical sections perpendicular to the strike of the formation, mainly from the crosscuts and from surface.

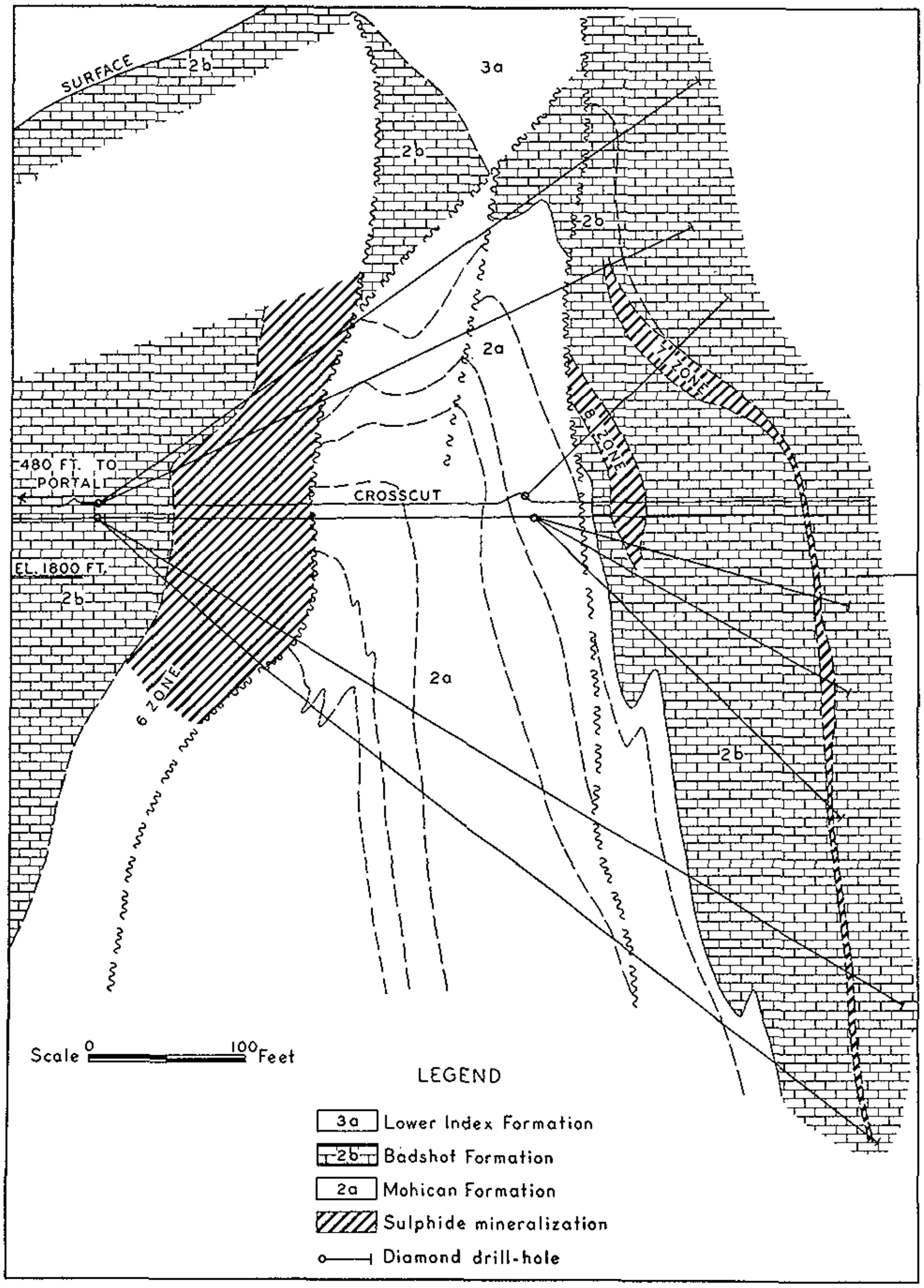

Figure 17. Vertical section along the main crosscut of the Duncan mine, from a drawing of the Consolidated company.

No. 7 zone is a steeply dipping tabular body averaging 15 to 20 feet thick along the western contact of the siliceous dolomite. The zone as indicated by drilling plunges about 7 degrees to the north and is about 400 feet high. It has been followed for 3,000 feet in the drift and found in drilling beyond. The zone is layered, with a western layer in which dolomite, pyrite, and sphalerite are found in fairly well-marked bands; a central layer with lenticular masses of pyrite, galena, and sphalerite in carbonate layers associated with fine-grained quartz; and an eastern siliceous layer in which pyrite and sphalerite are the dominant sulphides. Some bands of sulphides within the layers follow small discontinuous, nearly isoclinal folds which plunge to the north at low angles. Bands of sulphides are a fraction of an inch to a few inches thick, and the grains of sulphides within them are generally less than 1 millimetre across.

No. 5 zone is below and to the south of No. 7 zone along the same western contact of the siliceous dolomite. It has the same plunge as No. 7 zone and is separated from it by a zone along the contact about 200 feet high in which there is only scattered sulphide mineralization.

No. 8 zone is a relatively small lens in the upper dolomite about 100 feet west of No. 7 zone. It dips at moderate angles to the east and, although not fully outlined, is 300 to 400 feet high parallel to the dip. It plunges to the north and appears to be offset on a steeply dipping strike fault above the main crosscut. Pyrite and sphalerite are the main sulphides, and galena has been found only in polished sections.

No. 6 zone is 300 to 400 feet west of No. 7 zone and is the most westerly and the largest zone found in the mine. The dominant sulphide is pyrite, with minor amounts of sphalerite and galena. Pyrrhotite is present locally in bands an inch to a few inches wide. The zone is lenticular in cross-section, approximately 300 feet high and 20 to 100 feet thick. The zone has been found in drilling for 3,000 feet along the plunge which is at low angles to the north, parallel to that of the other zones. The zone in the main crosscut is bounded on the east and probably offest by a westerly dipping fault (*see* Fig. 17). Most of the mineralization is uniformly fine-grained pyrite with varying small amouts of galena and sphalerite disseminated in closely spaced thin lenses or bands in siliceous dolomite. The siliceous dolomite appears to form a tight syncline. Pyrite near the fault on the eastern side locally forms rounded clusters resembling a sheared breccia. In the trough of the syncline it occurs in massive layers associated with limestone and siliceous dolomite.

Studies by Muraro of the textures of the sulphides, mainly from the zones in the Duncan mine, have shown that the pyrite is older than the galena and sphalerite, and that the pyrite is crushed and deformed, whereas the galena and sphalerite are not. The pyrrhotite in No. 6 zone is not obviously deformed and at least is partly formed by replacement of pyrite.

No. 2 zone, exposed in trenches and small bluffs near the crest of the ridge between Glacier Creek and Duncan Lake, consists of fine-grained galena, sphalerite, and pyrite in thin tightly folded layers of crystalline limestone in the lower part of the upper dolomite. The sulphides are in lenticular masses along the crests and troughs of small folds which plunge about north 20 degrees west at 10 to 15 degrees. Trenching has exposed several mineralized zones a few feet in diameter extending several tens of feet along the plunge. Drilling has indicated that the zones have small cross-sectional dimensions, and no significant mineralization has been found below the outcrop.

No. 1 zone is well exposed in the adit near Glacier Creek driven by Lardeau Lead & Zinc Mines Ltd. The adit was collared at an elevation of about 2,550 feet just below a zone of sulphides in dolomite exposed by trenching (*see* Plate XXII). It was driven about 650 feet in an average direction of north 15 degrees west, essentially along the strike of the mineralized zone. Three short crosscuts were driven to the east across the zone. The zone is in grey massive, banded, or flecked dolomite, probably in the lower part of the upper dolomite of the Badshot Formation. The sulphides are fine- to medium-grained pyrite, sphalerite, and galena in bands, lenses, and locally irregular veins of white crystalline calcite. Much of the calcite is like that found in the other zones, though it is somewhat coarser grained and some is clearly in veins in which coarse sphalerite, cubes of pyrite, and crystals of quartz appear to have been deposited along the walls of cavities. The adit follows a fairly persistent zone of mineralization up to 10 feet wide and, judging from surface exposures, more than 100 feet high. It dips steeply to the east and probably plunges at low angles to the north, and is known to be at least 300 feet long. Scattered mineralization over widths of several tens of feet has been found to the east and north of this persistent zone, but as yet a continuous mineralized zone has not been defined. Two samples taken by the writer assayed: Lead, 0.17 per cent; zinc, 1.8 per cent, across a width of 10 feet, and lead, 0.44 per cent; zinc, 4.2 per cent, across a width of 8 feet. Company assays indicate an average grade considerably higher than the grade of these samples.

[References: *Minister of Mines, B.C.*, Ann. Rept., 1926, p. 267; *Geol. Surv., Canada, Mem.* 161, p. 95; Muraro, 1962.]

Grizzly

The Grizzly Crown-granted mineral claim is on the west side of Lardeau Ridge 5½ miles north of Marblehead. It is owned by Thunderbird Mines Ltd., of Seattle. The property is an old one, but there are no published records of its history. The workings consist of old trenches, a shallow shaft, and a short adit, now caved. They follow a quartz vein in fine-grained green schists of the Index Formation. The schists have a low dip to the northeast, and the vein strikes north 5 degrees west and is essentially vertical. A narrow olivine lamprophyre dyke follows the eastern wall of the vein.

The workings extend for about 400 feet along the vein, but only in the southern part is the vein exposed. In the shaft it is 6 to 7 feet thick. Three inches of quartz containing tetrahedrite, chalcopyrite, and pyrite lies along the western edge of the vein, and a sample of this material assayed: Gold, trace; silver, 23.8 oz. per ton; and copper, 1.05 per cent. The remainder of the vein is massive quartz with scattered pyrite and lenses of altered wallrock which are rusty and calcareous and also contain pyrite. A sample across 2½ feet made up of quartz, pyrite, and altered wallrock assayed only traces of gold, silver, and copper. Between 1 and 2 tons of broken quartz mineralized with pyrite and some chalcopyrite and tetrahedrite is sorted on a dump near the shaft. South of the shaft the vein is poorly exposed in a long trench, and in the southernmost exposure it is 3 feet wide and contains scattered pyrite. The vein is not exposed in the workings north of the shaft but, judging from material on the dumps consisting of narrow quartz veins in altered wallrock, the massive quartz thins rapidly to the north.

Lavina

The Lavina property consists of six Crown-granted claims owned by Leamac Petroleums Ltd., of Calgary. They cover showings of lead and zinc on the crest of Lavina Ridge near Lavina Lookout that were worked many years ago but on which no work has been done since about 1927. The property was discovered in 1898, and the first shipment of silver-rich lead ore was made in 1901 by rawhiding it down a steep trail to Hamill Creek. Another shipment was made in 1902, and work continued on the property until about 1905. The property was reopened in 1917, and ore was shipped by lessees in 1918. It was worked again between 1924 and 1927, when another shipment was made. Judging from the published figures (p. 65), these shipments carried 50 to 70 per cent lead and as much as 50 ounces per ton of silver.

The showings are in limestone and dolomite of the Badshot Formation on the eastern limb of the Duncan anticline. The formation strikes north 10 to 15 degrees west and dips between 35 and 60 degrees to the east. The main workings are east of the Lavina Lookout and consist of two interconnected adits on the north slope of Lavina Ridge, one at 7,215 feet and the other at 7,380 feet elevation.* They are described in detail by H. C. Gunning (1929), and there appears to have been little or no work done on them since his visit. The showings consist of a series of lenticular veins a few inches thick containing fine- to medium-grained galena and several lenses of gossan in dolomite and limestone. They appear to be parallel to the strike but to dip more steeply than the formations. The dolomite in which the mineralization occurs is west of a layer of fine-grained grey calcareous mica schist (biotite schist of Gunning's report) 10 to 25 feet thick, which in turn is west of and underlies dark-grey siliceous dolomite at the top of the Badshot Formation. Neither the veins nor the lenses of gossan appear to continue more than a few tens of feet parallel to either dip or strike. Mineralized dolomite is found for about 100 feet north and for about 100 feet below the crest of the ridge and extends south along strike down the southern slope of Lavina Ridge for a distance of a few hundred feet and to an elevation of 350 feet below the crest of the ridge. The workings on the south slope are badly caved and expose gossan zones in limestone and dolomite in which nodules of anglesite, cerrusite, and minor galena can be found.

Southwest of the Lookout and at the top of the steep western slope of Lavina Ridge an adit has been driven in grey and white banded crystalline limestone 51 feet in a direction of north 28 degrees east. A steeply dipping fracture follows the west wall of the adit, and along it lenses lying parallel to the banding contain disseminated galena. As exposed in the adit wall, they are a few inches thick and a few feet long. Old trenches 30 to 40 feet above and northeast of the adit portal expose a lenticular quartz vein locally more than a foot thick lying along the upper contact of the limestone with grey schist. In the quartz vein, as well as along the contact where there is no quartz, are small lenses of galena.

[Reference: Gunning, H. C., 1929, pp. 105–108.]

Mag

The Mag property consists of about 20 claims held by record by The Consolidated Mining and Smelting Company of Canada, Limited. They adjoin the Argenta on the north and cover the ridge and northwest slope of the ridge west of the Lavina Lookout. The claims are along the outcrop of the Badshot and Mohican Formations on the western limb of the Duncan anticline. The showings are on the steep northwest slope of the ridge between elevations of about 3,000 and 5,500 feet. The ground is thickly covered with small evergreen trees.

The Mag claims were located in 1959 by A. B. Mawer, prospector for the Consolidated company, as a result of systematic prospecting of the Badshot Formation based on geological knowledge gained on the Duncan property. Old trenches and two short adits found on the showings may date from about 1900, when some of the ground was covered by a property known as the Grand Republic. A tractor-road was built to the showings late in 1959, and in 1960 trenching and 3,323 feet of diamond drilling was done in 11 holes. The results were not encouraging, and no further work has been done.

The stratigraphic succession on the property is essentially the same as that on the Duncan property, except that carbonate members in the Mohican and the upper part of the Badshot are not entirely dolomite. Much more limestone is present and

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* The elevations of the adits are those given by Gunning (1929) and, from recent topographic maps, are estimated to be about 100 feet high in relation to mean sea-level.

the siliceous rocks are lenticular. The formations in general are overturned and dip at low to moderate angles to the east and northeast. They are complexly folded in a form that appears to be synclinal on the west and anticlinal on the east. These folds plunge to the northwest at a low angle and are more or less parallel in plunge to the slope of the hill. Consequently it is difficult to be certain of the form of the folds.

Mineralization exposed in road cuts and bulldozer trenches is found in dolomite of the Badshot Formation over a strike length of more than a mile. It consists of zones of gossan locally containing galena and sphalerite in more or less fractured and weathered dolomite. Diamond drilling encountered sulphides at no great depth but was hampered by broken ground and an abnormally low easterly dip. Three groups of showings are present—one between elevations of 3,300 and 4,700 feet and the others close to 5,000 feet elevation. Gossan on the surface in the lower group of showings is as much as 60 feet wide, and two samples taken by the writer assayed: Lead, 0.24 per cent, and zinc, 1.0 per cent, across 6 feet. Comparable grades are reported from assays of drill core. The fact that the folds, and hence probably also the long axes of the mineralized zones, plunge somewhat parallel to the slope of the hill makes it difficult to determine the continuity and form of the mineralized zones.

Moonshine

This property consists of two Crown-granted claims and several claims held by record by Willett Mines Ltd. (company office, 310–317 West Pender Street, Vancouver). Workings on the property consist of two short interconnected adits, a shaft, and several trenches between elevations of 2,200 and 2,500 feet, about 1 mile south of Lardeau. The lower adit at 2,230 feet elevation and the shaft which is above it and to the southwest were made many years ago, and the adit is now caved. Most recent work on the property was done between 1951 and 1957. During this time the upper adit at an elevation of 2,250 feet was driven, several trenches were dug, and considerable stoping was done.

The claims cover silver-lead mineralization in a fracture cutting limestone of the Badshot Formation. Near the workings the Badshot, which is grey and white crystalline limestone, overlies grey to brown micaceous quartzite of the upper part of the Marsh-Adams Formation. The rocks strike north 20 degrees west and dip at low angles to the west. The limestone forms steep bluffs above and south of the workings.

Mineralization is along a narrow discontinuous fracture which strikes uniformly at north 30 to 35 degrees east and dips 65 degrees to the northwest. The fracture contains massive galena, sphalerite, and minor chalcopyrite with more or less quartz. The sulphides are present as fillings of the fracture and replacement of the limestone. The quartz is mainly along the footwall of the vein. The vein has been mined for about 90 feet along the upper level and ranges from a few inches to about 6 feet thick. It is near the base of the limestone and appears to thicken toward the base and to pinch out upward. As presently exposed, it does not extend more than a few tens of feet above the base of the limestone. Within the vein are lenses of coarse massive sulphides, some of which are as much as 5 feet long and 1 foot wide. A chip sample across 6 feet assayed: Silver, 16.4 oz. per ton; lead, 33.26 per cent; zinc, 20.4 per cent; and copper 0.2 per cent. Production figures indicate an average grade of : Silver, 12.1 oz. per ton; lead, 19.2 per cent; zinc, 21.2 per cent.

[References: *Minister of Mines, B.C.,* Ann. Repts., 1951, p. 180; 1952, p. 194; 1956, p. 106; 1957, p. 60.]

Sal

The Sal property consists of 10 claims held by record by The Consolidated Mining and Smelting Company of Canada, Limited, covering lead-zinc mineralization in the Badshot Formation on the eastern limb of the Duncan anticline south of Mount Willet. As originally located in 1960 by A. B. Mawer, company prospector, three mineralized zones, the Sal A and Sal B zones south of Mount Willet and the Sal C zone northeast of Mount Willet, were covered by the claims, but in 1963 only the A and B zones are covered. The three zones are between elevations of 7,500 and 8,000 feet. In 1960 they were mapped and sampled, and the A and C zones were tested by a packsack diamond drill with 10 holes totalling 550 feet.

Mineralization occurs in the upper and lower dolomite members of the Badshot Formation (*see* p. 25). The upper part of the upper member is very siliceous but contains large lenses of dolomite relatively free of quartz. The formations strike uniformly north 20 degrees west and dip 60 to 70 degrees to the west. They are overturned; quartzites and schists of the Marsh-Adams and Mohican Formations in the core of the Duncan anticline are west of the Badshot and Lower Index Formations. Lineations in the rocks plunge to the north at 5 to 10 degrees, and it is presumed that the long axes of the mineralized zones are parallel to this plunge.

The Sal A zone is in an alpine basin facing southwestward and draining into Salisbury Creek. The rocks and mineralization are well exposed. Fine-grained pyrite with minor amounts of sphalerite and galena occur in narrow bands of white crystalline limestone in grey dolomite. One mineralized zone about 300 feet long is along a contact between dolomite and siliceous dolomite. The zone has a maximum thickness of 15 to 20 feet. Quartz veinlets in the dolomite near the zone locally contain clusters of medium-grained galena. Another zone aboue 30 feet thick in the lower dolomite consists of three layers each a few feet thick containing disseminated pyrite, sphalerite, and galena. This zone as exposed on a relatively horizontal surface is also about 300 feet long.

The Sal B zone (Plate VI) is in cliffs on the south side of the alpine basin at the head of Bulmer Creek. Only the part of the zone near the base of the cliffs is readily accessible. Two layers of very siliceous dolomite separated by sparsely mineralized dolomite are present at the base of the cliff. The two layers join a few hundred feet vertically up the cliff. The lower dolomite, which is west of the siliceous layers, contains bands of fine-grained disseminated pyrite with minor sphalerite and galena in white crystalline calcite and separated by barren grey dolomite. The bands are 2 to 4 feet thick and together make up a mineralized zone 35 to 40 feet thick.

Three samples of individual bands assayed: Lead, 1.27 per cent; zinc, 4.8 per cent, across 2½ feet; lead, 0.32 per cent; zinc, 1.0 per cent, across 2½ feet; and lead, 0.06 per cent; zinc, 0.4 per cent, across 3½ feet. This mineralized zone appears to continue up the cliff at least 200 feet, and because of the topography the length of the zone is not known.

The Sal C zone is on a steep easterly facing slope of Mount Willet less than half a mile north of the summit in an area of small rubbly bluffs between talus slides. Mineralization is very similar to that at the B zone and is mainly in the lower dolomite. Small well-defined folds plunging at low angles to the north contain some of the mineralization. Samples of the best mineralization assayed: Lead, 0.59 per cent; zinc, 6.3 per cent, across 3½ feet, and lead, 1.02 per cent; zinc, 1.8 per cent, across 2 feet. A poorly defined zone about 10 feet thick is exposed at a number of places over a length of about 300 feet, but because of extensive talus it is not certain that the mineralization is continuous between the exposures.

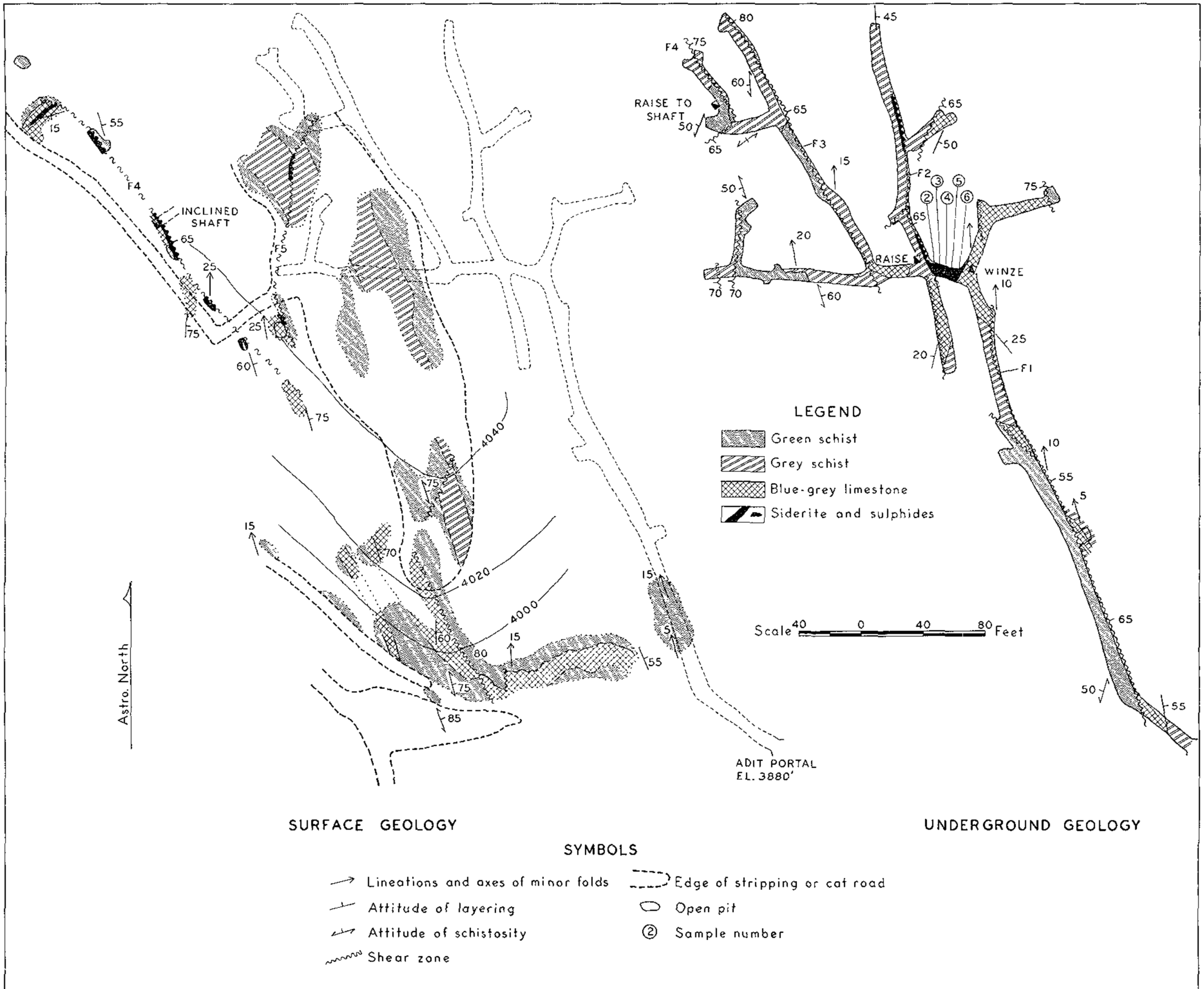

Figure 18. St. Patrick Mine

St. Patrick The St. Patrick property consists of one Crown-granted claim owned by New Hamil Silver-Lead Mines Ltd. (company office, 204, 569 Howe Street, Vancouver) and several adjoining claims held by record. The mine is near the top of the north slope of Hamill Creek at an elevation of about 4,000 feet, about half a mile northwest of the mouth of Clint Creek. The workings consist of an adit, an inclined shaft, and several trenches and bulldozer strippings made over a period of years to develop silver-lead-zinc mineralization in limestones and schists of the Index Formation.

The property was first developed in 1912 and has been worked at intervals. From 1917 to 1919 it was held by the British Alberta Mining Company, who shipped 21 tons of ore. In the late twenties it was worked by Jean Brochier, of Kaslo. In 1937 and 1938, 20 tons of ore was shipped. Altogether, production has been 42 tons, containing an average of 30 ounces of silver per ton, 36 per cent lead, and 17.5 per cent zinc. The present company, then called Hamil Silver-Lead Mines Ltd., built an access road from the Duncan River in 1950, and rehabilitated the camp and workings. In 1951 a raise connection was made between the adit and the shaft, a winze was sunk to a depth of 66 feet, and a small amount of drifting was done from the winze. Since 1951, intermittent work in the form of bulldozer stripping and small amounts of surface drilling have been done.

Rocks at the mine are dark-grey fine-grained mica schists, fine-grained light-green mica schists, and cream-coloured to greyish fine-grained limestones. Some of the green schists contain narrow lenses of whitish limestone. The rocks are highly contorted and are cut by a number of faults or shear zones. In the schists the dominant schistosity strikes north 15 to 25 degrees west and dips very steeply east. It is a second foliation which locally transects the first foliation shown by layers of limestone. The limestone has been folded on axes which plunge north 10 degrees west at 10 to 15 degrees. Mainly it dips steeply to the east, but locally on the crests of folds it dips gently to the north. One fold is exposed on surface 100 to 200 feet west and about 100 feet above the adit portal. Probably the same fold is encountered underground near the winze, where the limestone is replaced by siderite and sulphides. This fold, like others seen in cliffs to the east of the property, is a Phase II structure and is more or less step-like, rising toward the west.

A number of pronounced shear zones dipping steeply to the east and striking mainly between north and northwest have been followed in the workings, and the most important have been numbered (*see* Fig. 18). The shear zones consist of a few inches to a few feet of crushed and sheared rock, on either side of which the rocks are contorted and dragged. Commonly they transect the dominant foliation at an acute angle. The shear zones are faults with unknown but probably small displacement. A northerly striking fault exposed on surface about 100 feet east of the shaft has a left-hand offset of about 10 feet.

Mineralization occurs as scattered lenses along the faults and as a replacement of limestone. It consists of fine- to medium-grained galena and sphalerite in a gangue of fine-grained siderite. Along the faults the lenses of mineralization are either fine grained and massive or banded, crustified, and include layers of schist. Locally, massive galena in these zones is distorted, giving striking specimens with " gneissic " structure. Replacement mineralization in limestone has been found where a strong shear zone (F2), which is also mineralized, transects a layer of limestone near the crest of a fold. The limestone is contorted, but in general has a low dip to the north corresponding to the plunge of the fold. It is somewhat micaceous and is cut by a poorly developed cleavage. Replacement of the limestone by fine-grained siderite and medium-grained sphalerite and galena has taken place both along the cleavage and the layers within the limestone. Some of the sulphides and lenses of grey schist give the mineralized zone a lineation plunging at a low angle to the north, and it is concluded that the long axis of the replacement zone will plunge to the north.

The shear zone F2 is mineralized over a width of as much as 4 feet and a length along the strike of about 50 feet adjacent to the replacement mineralization. A raise and a short drift 24 feet above the adit show better mineralization than is exposed on the level. Sample 1 in the following table was taken in this short drift at the top of the raise.

Sample No.	Width	Gold	Silver	Lead	Zinc
	Ft.	Oz. per Ton	Oz. per Ton	Per Cent	Per Cent
1	4	Tr.	0.3	0.17	9.5
2	3	Tr.	0.6	7.11	11.9
3	3	Tr.	2.0	3.78	3.9
4	2	*Nil*	0.7	0.75	7.8
5	3.7	0.01	1.5	2.68	5.5
6	3.5	0.01	1.5	2.62	6.5

The replacement mineralization extends for about 30 feet east from the mineralization occurring along F2 and continues down the winze to the base of the limestone 28 feet below the level. The upper limit and the extent of mineralization in a north-south direction along the plunge are not known. Probably it does not extend more than a few feet above the level and a few tens of feet to the south. Assays of samples of replacement mineralization (Nos. 2, 3, 4, 5, and 6) taken along a horizontal line on the north wall of the adit across the highest grade of mineralization are given in the foregoing table.

The shear zone F2 contains a lens of siderite, sphalerite, and galena 70 to 110 feet north of the replacement mineralization. It has a maximum thickness of 2½ feet and contains lead and zinc in amounts comparable to those found farther south along the shear zone. Shear zone F3 contains scattered mineralization near the crosscut that dies out rapidly to the north. Shear zone F4 is followed by a raise to the bottom of the old shaft, but the raise and lower part of the shaft in 1962 were inaccessible. In the upper part of the shaft and along the shear zone exposed on surface that is presumed to be F4 there is a fairly persistent zone of siderite containing sphalerite, galena, and minor pyrite ranging from a few inches to 3 feet thick. Half a dozen pits have been made along this zone, each exposing some mineralization, but outcrops between them suggest that the zone is not continuously mineralized and that mineralization does not appear to continue to the north or south along strike from the workings. Another shear zone, F5, is exposed in trenches east of the zone in the shaft and has not been correlated with any shear underground. It strikes northward, and in a pit at the southern end contains a steeply dipping lens of siderite between limestone and green schist. To the north along the zone is a lens of massive sheared galena in dark-grey mica schist.

[References: Gunning, 1929, p. 50; *Minister of Mines, B.C.,* Ann. Rept., 1952, p. 193.]

Surprise

The Surprise property on Glacier Creek consists of four Crown-granted claims owned by W. F. Clark and associates, of Howser. The workings consist of three short adits between elevations of 3,500 and 3,700 feet, driven over a period of years to explore a number of quartz veins containing grey copper in dark-grey slate of the Lower Index Formation. The first published reference to the Surprise property is to work done in 1923, when 59 tons of silver ore was shipped. At that time and until about 1927 it was owned by F. A. Devereaux, of Victoria, and worked by residents of the area. Most of the level workings were driven during this period. In 1946 the property was owned by Joe Gallo, of Howser, and he and his associates worked the property at intervals until 1954, during which time a road was built and 1,259 tons of ore was shipped. The mine camp is on Glacier Creek, and the road extends up the hill northwest of the camp in a series of switchbacks to a point about 500 feet below the workings. Slides on the switchbacks and on the road along Glacier Creek about a mile from the camp made it impassable for vehicles in 1962.

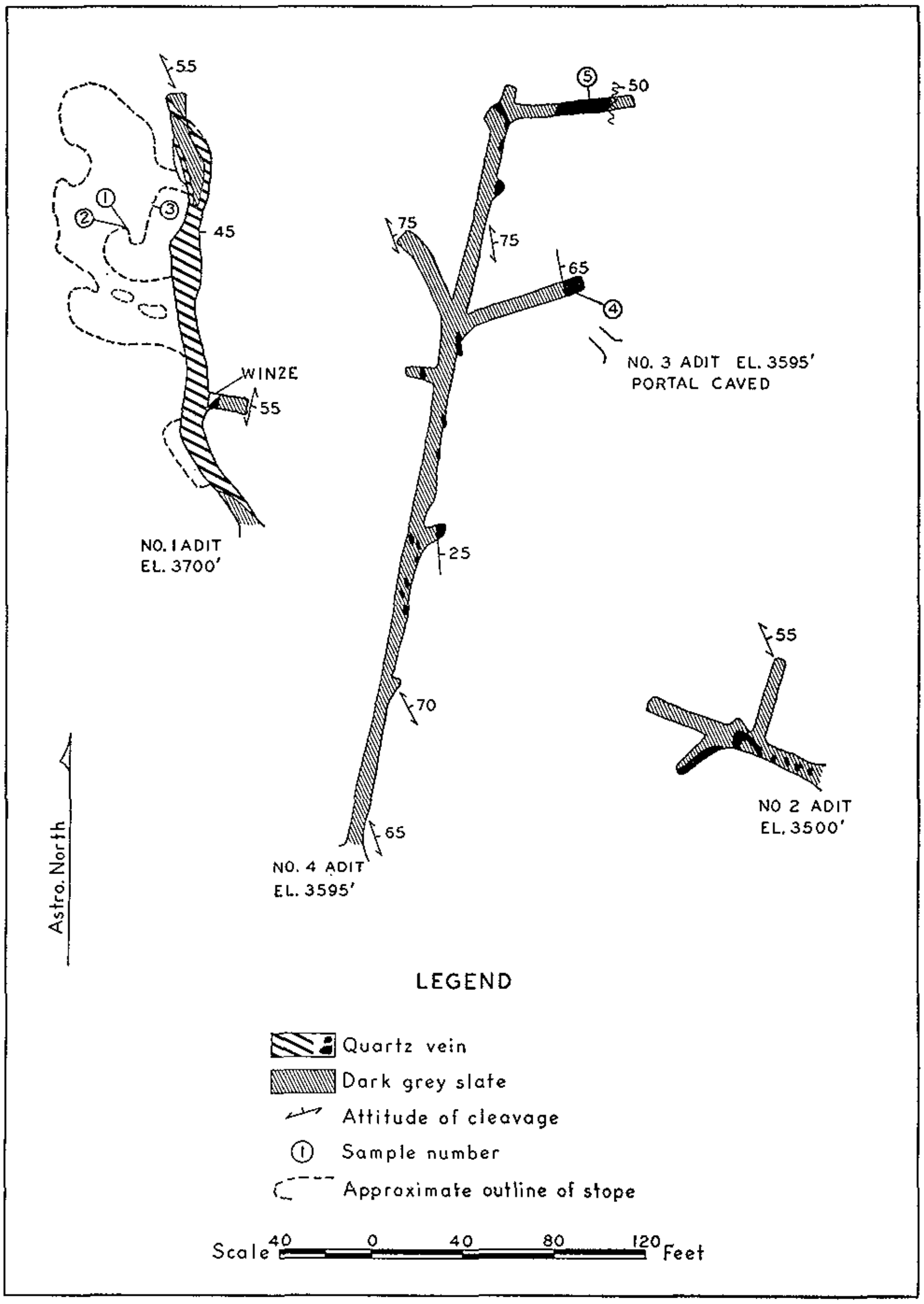

Figure 19. Underground workings, Surprise mine.

The showings are described in detail by Gunning (1929, p. 103), and the workings numbered in accordance with his report are shown on Figure 19, which is based on a compass and tape survey made in 1962. No. 3 adit is caved at the portal. The inner ends of both the crosscuts in No. 4 adit are close to the surface and to No. 3 adit.

Mineralization on the property consists of clusters and irregular masses of tetrahedrite in milky-white quartz. Sphalerite, galena, pyrite, and chalcopyrite are present in minor amounts. The tetrahedrite has weathered to give a striking azure-blue coating to the quartz on the mine dump and in outcrops. Elsewhere the quartz is white or rusty, coarsely crystalline, and more or less fractured.

Many lenticular quartz veins occur near the workings and are reported to continue up the hill to the north almost to the crest of the ridge between Glacier Creek and Duncan Lake. Only the vein exposed in No. 1 adit contains significant amounts of tetrahedrite. The veins are more or less parallel to the cleavage of the enclosing slates, but the average dip is less than the dip of the cleavage. Parts of the veins are parallel to the cleavage, and other parts break obliquely across it in both dip and strike. Near the vein the slates are contorted and sheared. Inclusions of slate are common in larger well-defined veins, and poorly defined veins made up of closely spaced lenses of quartz in slate are common.

The vein in No. 1 adit, which is followed on the level for about 200 feet, ranges from a few inches near the face to about 8 feet thick below the stopes. The average dip is 45 degrees to the east, and the strike varies from north 40 degrees west near the portal to due north in most of the adit. Near the face the vein splits and both branches thin toward the north. The vein has been stoped for about 90 feet up dip above the level. Tetrahedrite, which carries silver, occurs in irregular clusters and layers in shattered quartz. Assays of three samples taken in the stope in the highest-grade material left in pillars are given in the following table. Production statistics indicate a grade of 36.3 ounces of silver per ton. In mining, ore was sorted in the stopes, and it is reported that it was difficult to avoid dilution and the loss of fine tetrahedrite. A winze near the portal of the adit follows the vein down the dip where it branches and becomes thinner than above the level. Tetrahedrite is present 20 to 30 feet below the level in a vein less than 10 inches thick. On surface to the south and down a steep slope from the portal of No. 1 adit, what is probably the same vein thickens from about 1 foot to as much as 4 feet and pinches out entirely a few feet above the portal of No. 4 level. It contains very little tetrahedrite where exposed. A lens of quartz a few feet thick outcrops for 60 feet down the slope below the No. 4 portal.

Sample No.	Notes	Width	Gold	Silver	Copper
		Ft.	Oz. per Ton	Oz. per Ton	Per Cent
1	Hangingwall of vein	3.0	0.03	16.6	0.75
2	Footwall of vein below sample 1	4.5	0.02	50.8	1.33
3	Full vein width	3.7	0.04	20.0	0.68
4		4.5	Tr.	0.3	0.01
5	Shattered quartz and slate	5.0	Tr.	0.1	0.01
6		2.0	Tr.	6.4	0.13

Many quartz veins are present in No. 4 level, and it is not possible to correlate any one with the vein in No. 1 adit. They are shown diagrammatically on Figure 19, and the assays of two samples (4 and 5) are given in the table. Projection from surface indicates that the vein sampled is a large vein exposed on the surface 150 to 200 feet east of the vein in No. 1 adit. Underground it consists of shattered rusty quartz with many inclusions of black slate. On surface it is fairly massive white or rusty quartz locally containing layers of slate parallel to the walls. The strike is about north 30 degrees west and the dip between 45 and 60 degrees to the east. The quartz forms a wide outcrop on the western side of a small draw. The only tetrahedrite seen in this vein is in an open cut at about the level of No. 1 adit, from which some ore has been taken. It consists of a lens of copper-stained somewhat vuggy quartz with ribbons of grey schist and scattered grains of pyrite and tetrahedrite. As exposed in the face of the cut, it is about 2 feet thick and extends about 6 feet up the dip. Assays of a sample (6) are given in the table.

The No. 2 adit, which is not described by Gunning (1929), is on the footwall side of the thick vein exposed in the open cut. It is a short irregular working which encountered a stockwork of quartz lenses in contorted siliceous black slate. No definite vein is exposed. About 50 feet southwest of the portal of No. 2 adit is an old open cut exposing a lens of quartz, and on the dump of the cut and the dump at No. 2 adit, pieces of quartz are copper stained. No sulphides were seen in these workings.

[References: Gunning, 1929, p. 103; *Minister of Mines, B.C.,* Ann. Rept., 1927, p. 282.]

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1964

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Plate I. Duncan Lake from the south, Glacier Creek in the foreground and Howser on the raised delta, centre. Cliffs of dolomite in the distance on the east side of the lake are just south of the Duncan mine. No. 2 zone of the Duncan property is on the shoulder in right foreground.

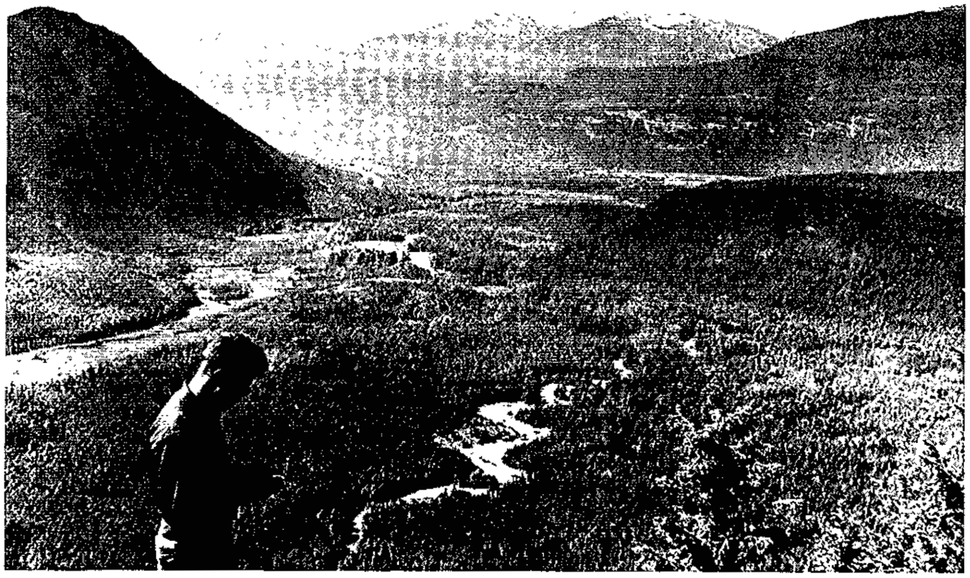


Plate II. The Duncan Valley looking southwest across the site of the proposed dam.

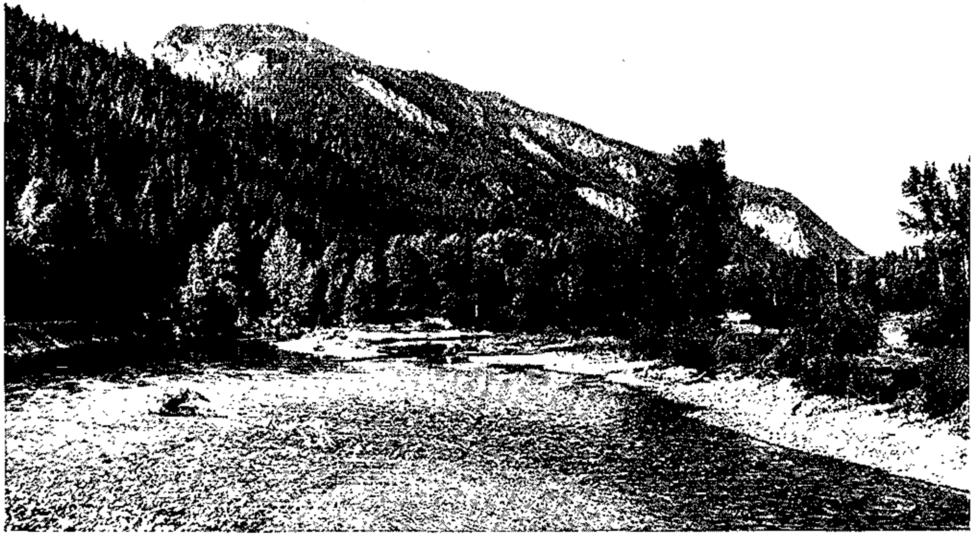


Plate III. Lardeau River looking northwest from Marblehead.

Plate IV. View looking north from Lavina Ridge across the valleys of McLeod and Glacier Creeks to glacier and peaks just beyond the map-area.

Plate V. Duncan Lake from the north; Kootenay Lake in the distance.

Plate VI. Mount Willet from the northeast showing the Sal C and Sal B zones of lead-zinc mineralization.

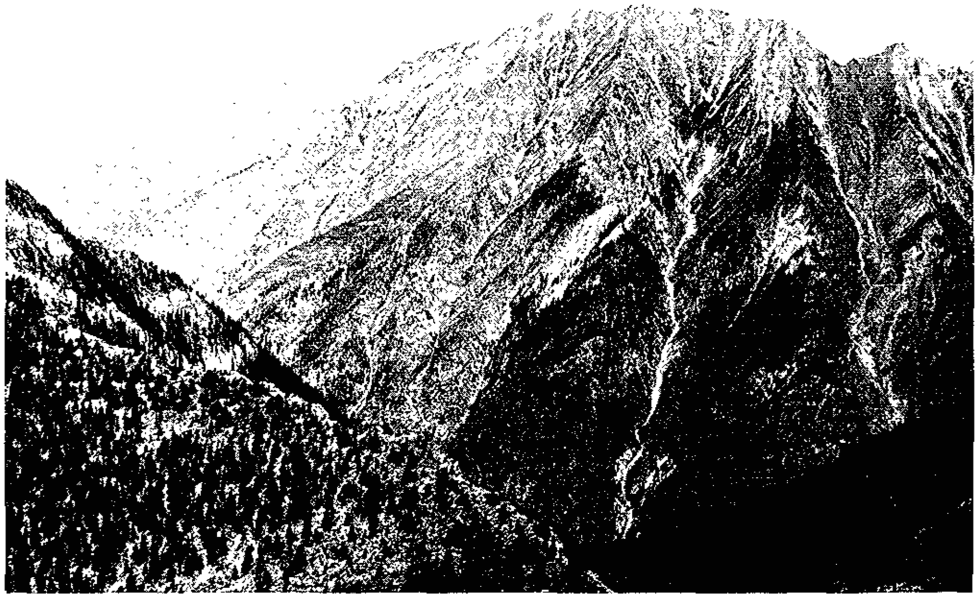


Plate VII. Comb Mountain from the south, showing the Comb Mountain antiform outlined by gently west-dipping quartzites and limestones on the southwestern slopes of the mountain (centre and left centre) and by a steeply west-dipping layer of limestone (right centre) (*see* Fig. 11).

Plate VIII. Lavina Ridge looking north across Hamill Creek, showing the Lavina synform and antiform (*see* Fig. 13).

Plate IX. Felsite sill in the green schists of the Index Formation.

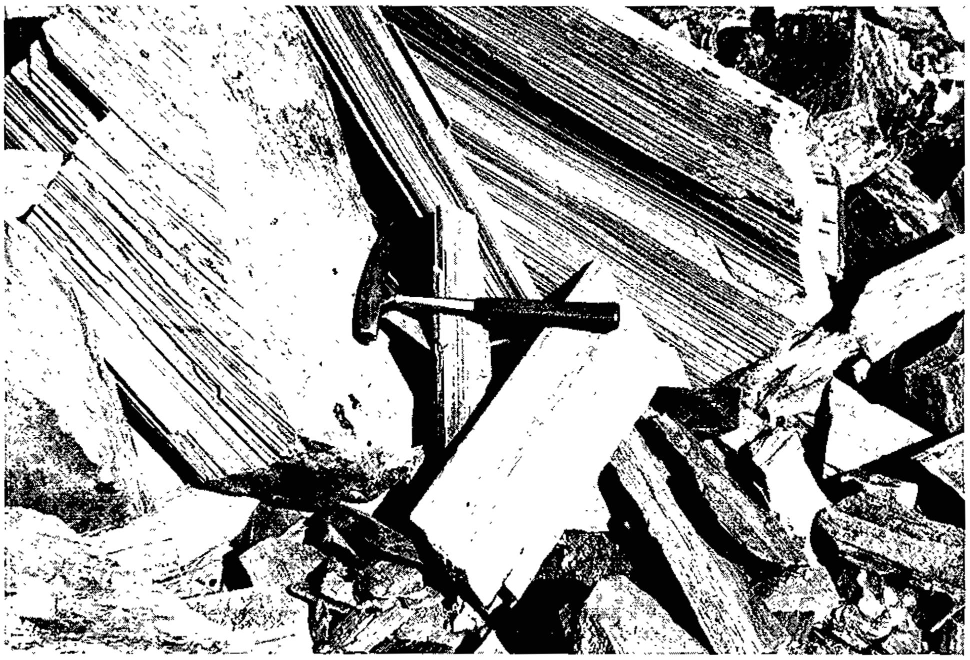


Plate X. Lineations in white quartzite of the Marsh-Adams Formation on Mount Willet.

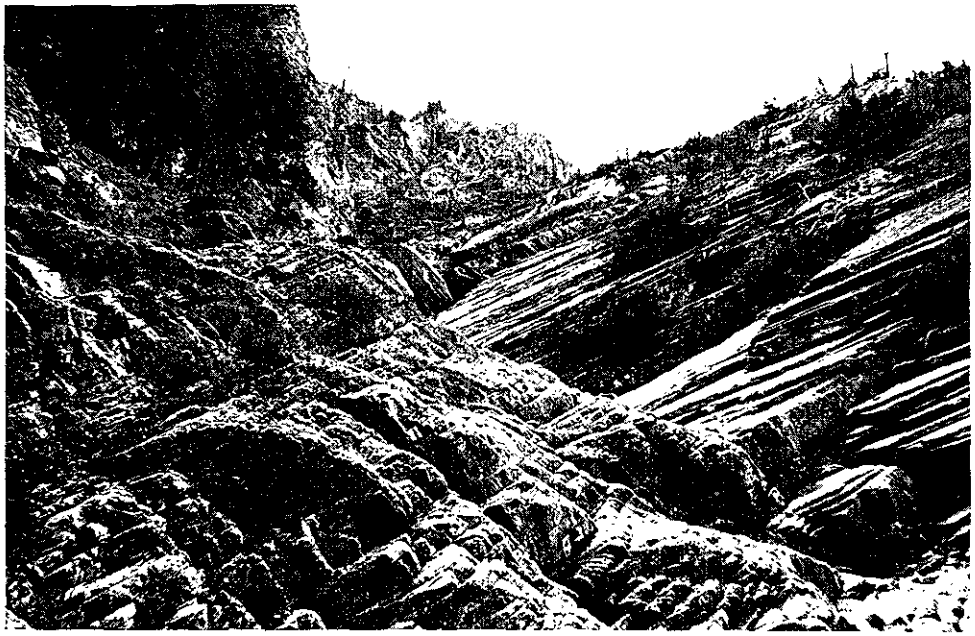
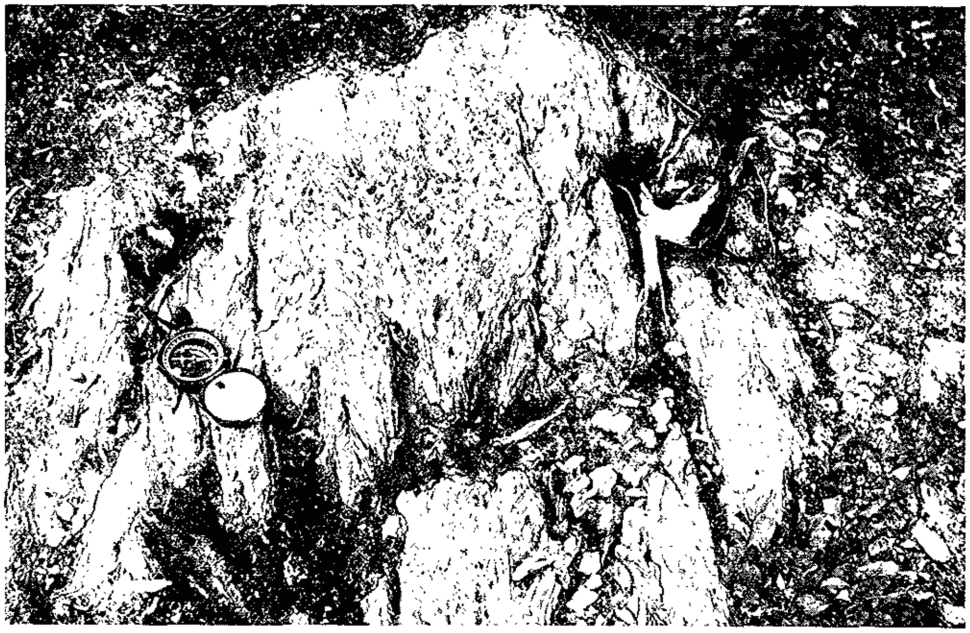


Plate XI. First foliation in the form of platy jointing following bedding in white quartzites of the Marsh-Adams Formation.

Plate XII. Grit and phyllite of the Broadview Formation west of the Lardeau Bluff, looking north. The bedding (first foliation) dips to the right and is crossed by a poorly developed cleavage (second foliation) dipping to the left.

Plate XIII. Contorted bedding (first foliation) transected by cleavage (second foliation) in micaceous quartzites of the Triune Formation.



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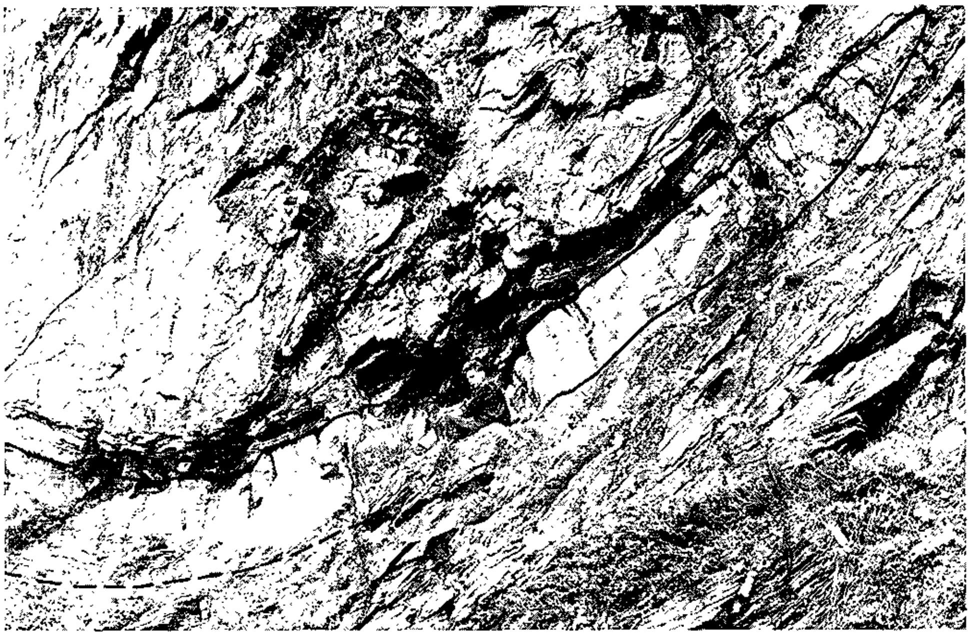

Plate XVII. Isoclinal Phase I fold outlined by limestone (white) at the base of the Mohican Formation. Minor Phase II folds can be seen in quartzites above the man and a larger Phase II synform is indicated by a flattening in dip of the limestone at left. View looking northward, roughly down the plunge of the folds.

Plate XVIII. Phase II folds in quartzites near the head of the south fork of Clint Creek, looking south.

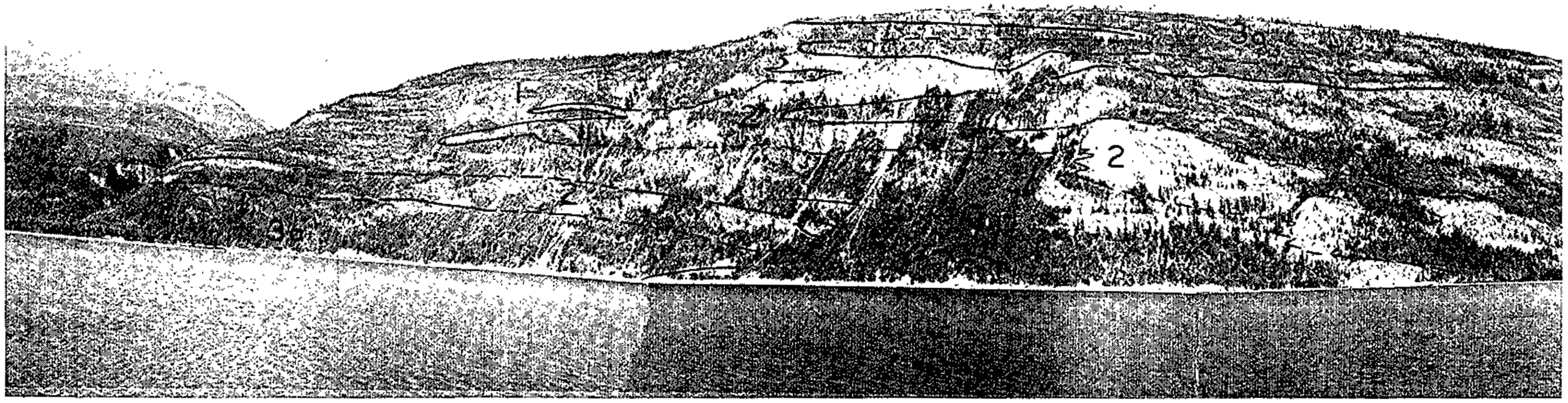

Plate XIX. Lardeau Bluff from Argenta, showing the complex patterns of outcrop of (1) Marsh-Adams, (2) Badshot and Mohican, and (3*a*) Lower Index Formations.

Plate XX. View looking north from the southeastern corner of the map-area toward Clint Creek and Comb Mountain (left of centre in distance). In the foreground a Phase II synform west of an antiform is outlined by the attitude of limestone lenses (lined in black): (1) Marsh-Adams, (2) Badshot(?) and Mohican, (3*a*) garnet mica schist of Index and Mohican Formations. Steeply west-dipping strike faults are inferred at A and B.

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Plate XXII. Contorted sulphide mineralization in dolomite of the Badshot Formation. Narrow dark layers contain disseminated pyrite, sphalerite, and galena in fine- to medium-grained calcite. The white and light-grey layers are dolomite.

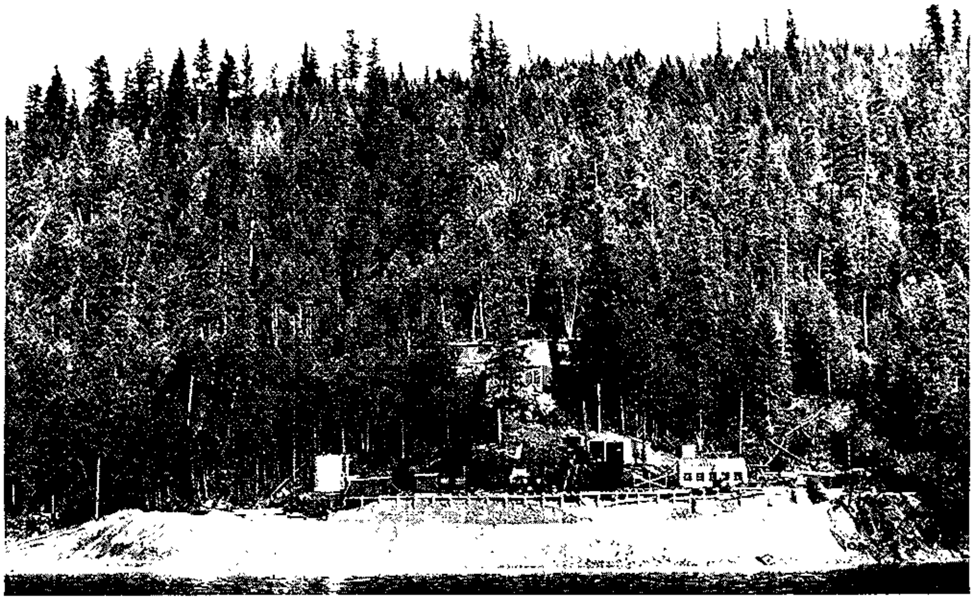

Plate XXIII. Duncan mine, August, 1960; portal of the main crosscut at lower right.

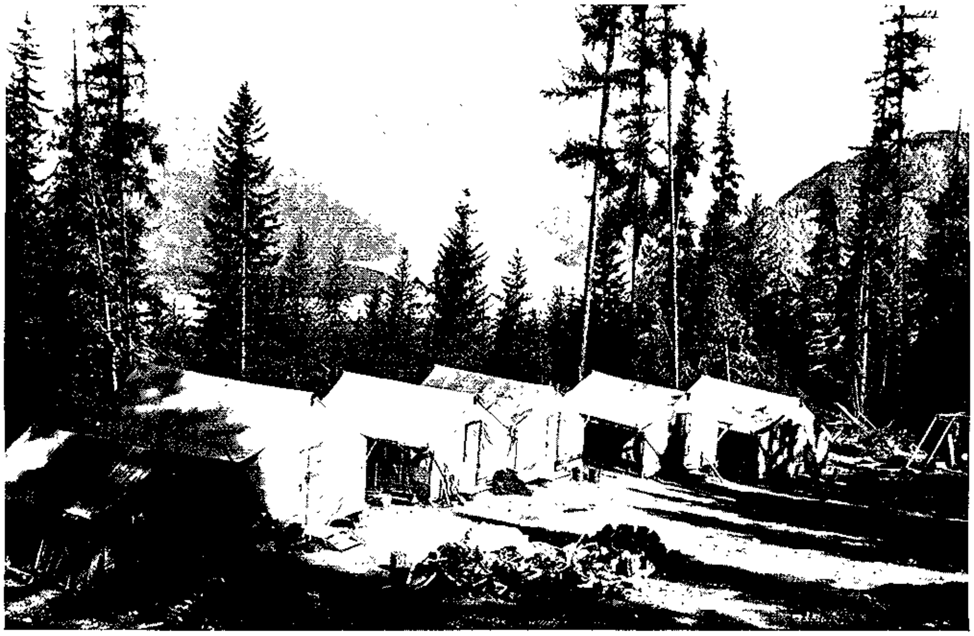

Plate XXIV. Diamond-drill camp on the Mag property, August, 1960, looking northwest across Duncan Lake.

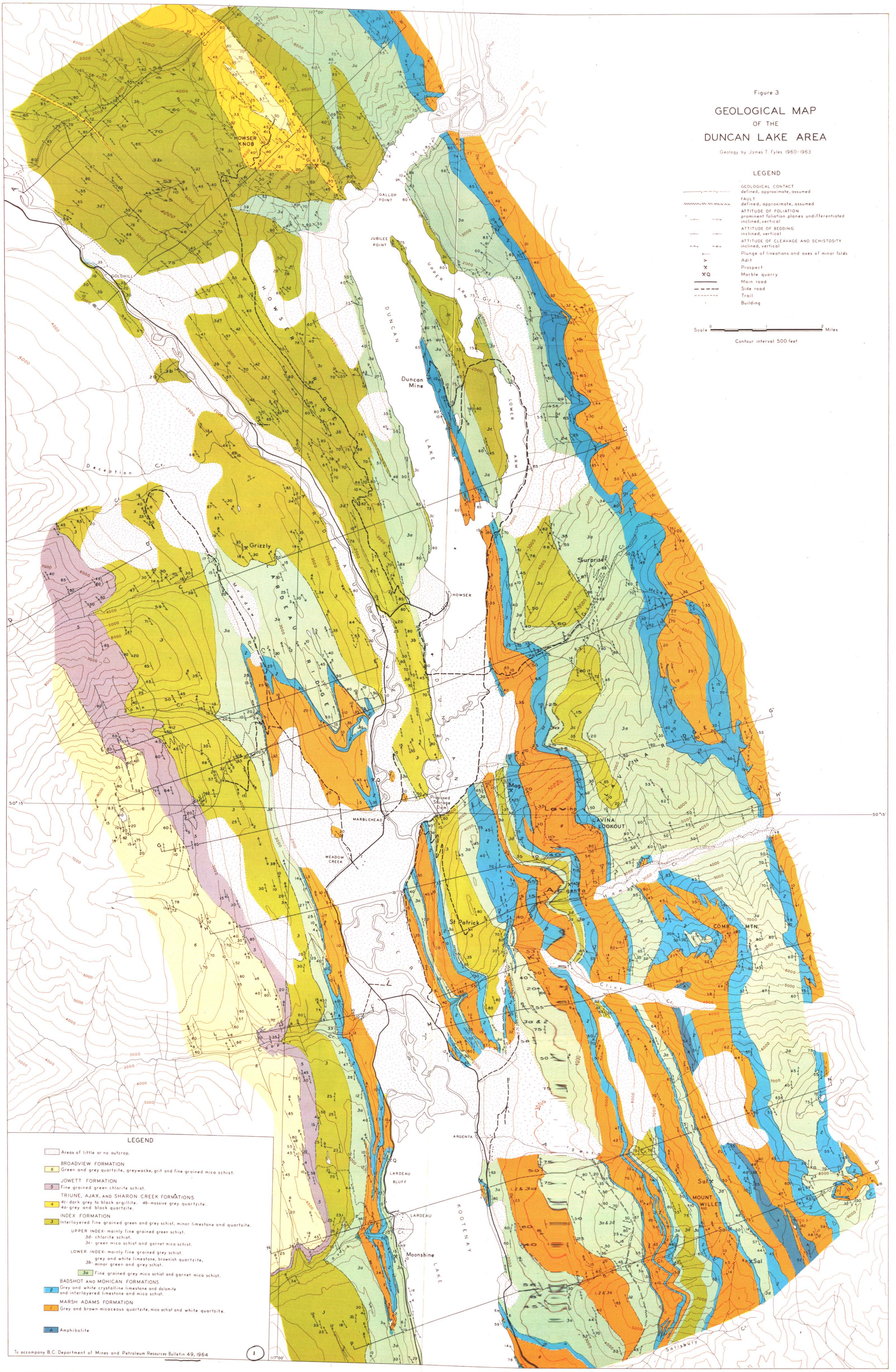

Figure 3

GEOLOGICAL MAP OF THE DUNCAN LAKE AREA

Geology by James T. Fyles 1960-1963

LEGEND

———, — — —, ······	GEOLOGICAL CONTACT defined, approximate, assumed
〰〰, 〰 〰, ∼ ∼	FAULT defined, approximate, assumed
⊥ ↔	ATTITUDE OF FOLIATION prominent foliation planes undifferentiated inclined, vertical
⊥ +	ATTITUDE OF BEDDING inclined, vertical
⊥ ‡	ATTITUDE OF CLEAVAGE AND SCHISTOSITY inclined, vertical
←	Plunge of lineations and axes of minor folds
≻	Adit
x	Prospect
xQ	Marble quarry
———	Main road
— — —	Side road
- - - -	Trail
·	Building

Scale 0 1 2 Miles

Contour interval 500 feet

LEGEND

▨	Areas of little or no outcrop.
6	BROADVIEW FORMATION Green and grey quartzite, greywacke, grit and fine grained mica schist.
5	JOWETT FORMATION Fine grained green chlorite schist.
4	TRIUNE, AJAX, AND SHARON CREEK FORMATIONS 4c- dark grey to black argillite. 4b- massive grey quartzite. 4a- grey and black quartzite.
3	INDEX FORMATION Interlayered fine grained green and grey schist, minor limestone and quartzite. UPPER INDEX: mainly fine grained green schist. 3d- chlorite schist. 3c- green mica schist and garnet mica schist. LOWER INDEX: mainly fine grained grey schist. 3b- grey and white limestone, brownish quartzite, minor green and grey schist.
3a	Fine grained grey mica schist and garnet mica schist.
2	BADSHOT AND MOHICAN FORMATIONS Grey and white crystalline limestone and dolomite and interlayered limestone and mica schist.
1	MARSH ADAMS FORMATION Grey and brown micaceous quartzite, mica schist and white quartzite.
A	Amphibolite

To accompany B.C. Department of Mines and Petroleum Resources Bulletin 49, 1964

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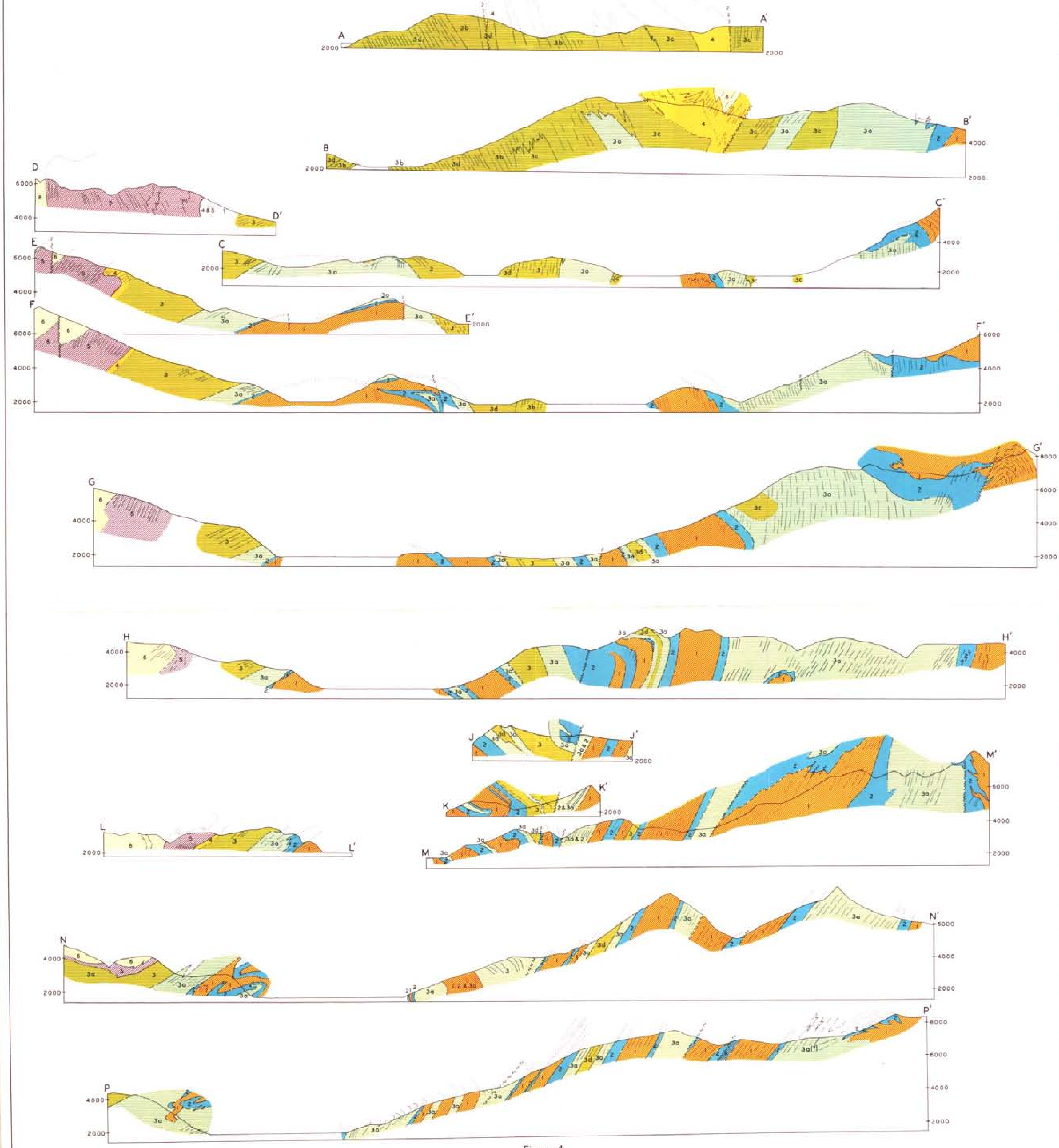

Figure 4

DIAGRAMMATIC STRUCTURAL SECTIONS

DUNCAN LAKE AREA

Scale 2000 0 2000 4000 6000 Feet

Horizontal and vertical

For legend see Figure 3

To accompany B.C. Department of Mines and Petroleum Resources Bulletin 49, 1964.

②