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Geology of the

Cowichan Lake Area

Vancouver Island, British Columbia

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CONTENTS

ILLUSTRATIONS

PHOTOGRAPHS

Geology of the Cowichan Lake Area, Vancouver Island, British Columbia

SUMMARY

1. The area referred to in this report as the Cowichan Lake area includes about 280 square miles of mountainous country on southern Vancouver Island lying mainly north and northwest of Cowichan Lake.

2. Fault-line scarps and fault-controlled valleys are the most prominent physiographic features of the region. The north side of Cowichan Lake is a fault-line scarp; and Rift Creek, the west fork of Cottonwood Creek, and the upper part of South Nanaimo River flow in fault-controlled valleys.

3. The continental ice-sheet covered the entire region. The ice appears to have moved southward.

4. The oldest rocks in the area belong to the Sicker group. They include thin-bedded, cherty, argillaceous, and feldspathic tuffs; limestones; coarse and fine breccias; and minor intercalated amygdaloidal basalt flows.

5. Crinoidal limestones at the top of the Sicker group contain Lower Permian fossils.

6. The Sicker group is conformably or disconformably overlain by the Vancouver group.

7. The lower part of the Vancouver group is made up of a thick sequence of massive, pillow, and amygdaloidal basalt flows and related sills, dykes, and irregular bodies of diabase. The intrusive masses are equivalent to the Sicker gabbro-diorite-porphyrite described by Clapp.

8. The upper part of the Vancouver group includes the Sutton limestone, which contains Upper Triassic fossils, and an overlying sequence of clastic sediments.

9. Rocks of the Sicker and Vancouver groups are highly deformed into northwesterly trending folds, many of which are overturned with both limbs dipping southwestward.

10. Plutons of Saanich granodiorite belonging to the Coast intrusions cut the Sicker and Vancouver groups. They are dominantly quartz diorite and granodiorite, but a roof facies of granite and aplogranite occurs near the top of Mount Buttle.

11. The plutons are mainly steeply dipping, elongate bodies less than 2 miles wide and several miles long. In cross-section they cut across structures in the pre-granitic rocks; in plan, long axes are parallel to fold axes in the older rocks.

12. Close to plutons of granodiorite the pre-granitic basaltic rocks have been metamorphosed and exhibit granoblastic textures and contain minerals characteristic of the granodiorite. Farther from granodiorite plutons, pre-granitic rocks have undergone a low grade of regional metamorphism that appears to be spatially related to the granodiorite.

13. Erosional remnants of Upper Cretaceous detrital sediments belonging to the Nanaimo group unconformably overlie the Saanich granodiorite and pre-granitic rocks.

14. The Nanaimo group has been gently folded and displaced by steeply dipping faults. Most of the movement on the faults appears to be parallel to the dip, and the dip-slip on several is more than 1,000 feet.

15. Small irregular masses of gabbro, possibly of Tertiary age, intrude rocks of the Sicker group and the Saanich granodiorite.

16. Copper has been shipped from the Blue Grouse property on the south side of Cowichan Lake, and manganese from the Hill 60 deposit 4 miles east of Lake Cowichan.

17. Copper occurs in chalcopyrite-skarn deposits at the Blue Grouse property and on the divide between Widow Creek and Chemainus River.

18. Quartz veins near bodies of granodiorite commonly contain molybdenite. On the Allies property on Mount Buttle, quartz-molybdenite veins have been prospected by trenches and open pits.

19. Shear zones in massive volcanics of the Vancouver group on El Capitan and the northeast slopes of Mount Service contain sulphides and gold. They have been explored by underground workings on the Silver Leaf and El Capitan properties.

20. At many places cherty rocks of the Sicker group contain manganese silicates, mainly rhodonite and manganese garnets. Within a few feet of the surface the silicates have been oxidized, and siliceous manganese oxides have been mined at the Hill 60 deposit.

CHAPTER I.—INTRODUCTION

The area referred to in this report as the Cowichan Lake area comprises about 280 square miles of mountainous country on southern Vancouver Island, lying within the Victoria and Nanaimo Mining Divisions. It is an irregular northwesterly trending area, 10 to 15 miles wide, bounded on the east by the 124th meridian of west longitude, and extending along the northeast side of Cowichan Lake about 30 miles to the headwaters of the west forks of Nitinat River. All of the Cowichan Lake area lies within the Esquimalt and Nanaimo Railway land grant.

Logging is the main industry of the region, and the communities of Lake Cowichan, Honeymoon Bay, Mesachie Lake, and Youbou are the principal logging towns. During World War I and in recent years, copper has been mined on the Blue Grouse property near Honeymoon Bay. For many years, work has been done on several prospects in the hope of producing copper, gold, molybdenum, and manganese.

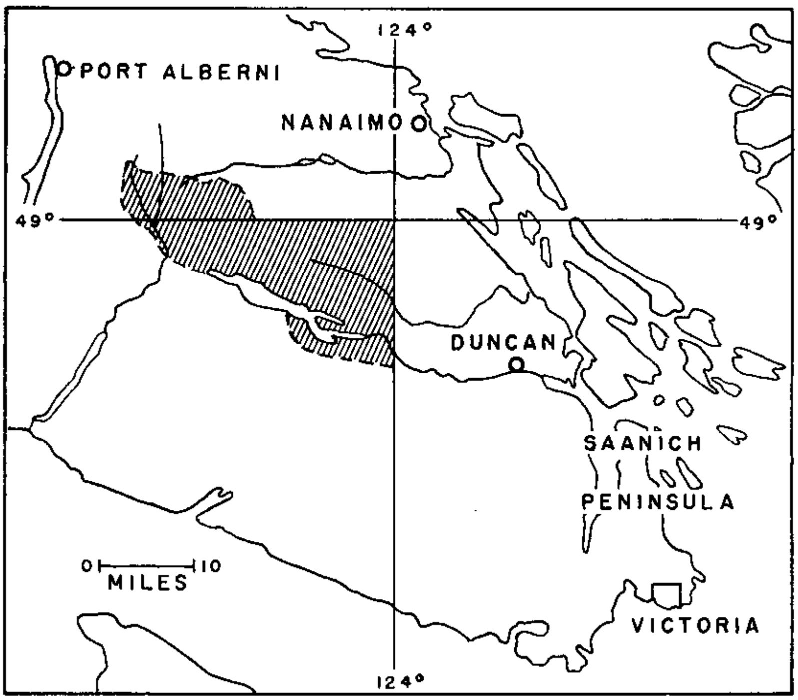

Figure 1. Index map of southern Vancouver Island showing the Cowichan Lake area.

Most of the area can be reached from the village of Lake Cowichan at the outlet of Cowichan Lake. The northwest corner of the area, however, in the summer of 1951, was more accessible from logging-roads running southeast from Port Alberni than from Cowichan Lake. A main highway runs from the town of Duncan to Lake Cowichan, and local public roads extend along the northeast and southwest sides of Cowichan Lake as far as Youbou and Honeymoon Bay. Beyond the public roads, private logging-roads, in various stages of repair, extend up logged-off valleys, and foot-trails follow many of the timbered valleys. The track of the Canadian National Railway runs along the north side of the lake as far as Nitinat River, and the railway maintains a freight service as far as Youbou. Speeders and logging-trains of the British Columbia Forest Products Limited run west from Youbou, on the Canadian National Railway track.

PREVIOUS GEOLOGICAL WORK

A discussion and bibliography of geological work on southern Vancouver Island before 1912 is given by C. H. Clapp in Memoir 13 of the Geological Survey of Canada, pages 4 to 8. Clapp's preliminary account of the general geology of about 4,000 square miles of southern Vancouver Island is also contained in Memoir 13. This reconnaissance included several traverses in the Cowichan Lake area, and a study of the shoreline geology of Cowichan Lake. Since the preliminary report, no geological information has been published other than accounts of the geology near mining prospects which have appeared from time to time in Annual Reports of the British Columbia Minister of Mines. East of the Cowichan Lake area, Clapp and others carried on geological mapping between 1910 and 1913, and the results have been published in three memoirs of the Geological Survey of Canada (Clapp, 1913; Clapp, 1914; Clapp and Cooke, 1917).

During the summer of 1939, trainees of the Dominion-Provincial Mining Training Project prospected in the Cowichan Lake area and discovered or rediscovered several manganese occurrences. A geological sketch-map and a short report on the manganese deposits were prepared and made available to the writer, but were not published. Northwest of the Cowichan Lake area, in the region between Museum Creek and China Creek, an area known as the China Creek area was mapped for the British Columbia Department of Mines by J. S. Stevenson during the summer of 1941 (Stevenson, 1944). The northwest edge of the Cowichan Lake area adjoins the southeast edge of the China Creek area.

FIELD WORK AND ACKNOWLEDGMENTS

This report is based on studies made by the writer during about three months in each of the summers of 1948, 1949, and 1950, and about one month in the early autumn of 1951. Plotting in the field was done on prints of manuscript maps supplied by the British Columbia Department of Lands and Forests, on a scale of one-half mile equal to 1 inch. The geology was surveyed by compass and pace traverses, and critical points were located in the field by resection and plotting from air photographs.

The writer acknowledges his indebtedness to various residents of the district, in particular to Duncan Powel, of Duncan, and A. H. Lomas, of Victoria, whose friendly help and knowledge of the country, gained through years of prospecting, proved invaluable. Thanks are due to officials of various logging companies for use of their roads, especially to the British Columbia Forest Products Limited for use of its speeder west of Youbou. The writer was assisted in the field in 1948 by C. A. McGregor, in 1949 by K. C. Lucas and R. H. Beaton, and in 1950 by A. E. Thompson. Helpful suggestions during the laboratory work and preparation of the manuscript were given by Drs. F. F. Grout, C. H. Behre, Jr., and A. Poldervaart, of Columbia University. Fossils sent to the Geological Survey of Canada were identified by Drs. F. H. McLearn, Peter Harker, and J. L. Usher, while a suite of crinoidal limestone was examined by Dr. M. L. Thompson, of the University of Wisconsin.

PHYSICAL FEATURES

The Cowichan Lake area includes the most easterly mountainous region of Vancouver Island. The low rounded hills of the southeast end of Vancouver Island rise gently westward to the rocky summits of Mount Whymper and Mount Landalt, 8 to 10 miles within the Cowichan Lake area. Similar 4,000- to 5,000-foot peaks with bluffy summits slightly above timberline are common throughout the area and form the southern end of the Vancouver Island mountain ranges. Forests of Douglas fir, hemlock, and red cedar cover the lower levels, and large areas, especially near Cowichan Lake, have been logged. Above elevations of about 4,000 feet the heavy timber gives way to rocky bluffs or heather-covered meadows studded with clumps of alpine trees. Hillsides are steep, and outcrops are numerous both on the hillsides and in creek bottoms.

Bedrock geology has obviously controlled the formation of a few outstanding topographic features of the region. In general, easily eroded rocks such as the Upper Cretaceous sediments underlie regions of low relief or form benches on otherwise steep hillsides (*see* Fig. 2). The more resistant rocks, in particular the Triassic basalts, stand up as bold peaks such as Mount Whymper and El Capitan or as lower bluffy ridges like those at the east end of Cowichan Lake.

The most outstanding physiographic features of the region are the fault-line scarps and fault-controlled valleys which are common throughout the Cowichan Lake area and appear to be widespread elsewhere on southern Vancouver Island. The northeast side of Cowichan Lake is typical. The lake lies in a northwesterly trending valley, the northeast side of which is markedly steep and straight. Toward the east end of the lake, hills on the northeast side rise from the lake at 550 feet above sea-level to elevations of 3,000 to 3,500 feet. Between elevations of 1,000 and 2,000 feet on the valley wall the average slope is 35 to 40 degrees. A steeply dipping fault striking parallel to the north wall of the valley is exposed in Meade Creek, and a similar fault is exposed near the mouth of Shaw Creek. The attitude and position of the Upper Cretaceous sediments on the lakeshore and above the valley wall indicate that a fault with the south side downthrown about 1,000 feet follows the base of the valley wall from near Lake Cowichan at least as far west as Youbou and has displaced the Upper Cretaceous sediments. Talus, alluvium, and glacial drift obscure the bedrock on the shore of the lake west of Youbou, but it is probable that a fault or series of faults intersecting one another at small angles are present throughout the length of the north side of the lake. The straight abrupt side of Cowichan Lake thus appears to be a fault-line scarp which originated in post-Upper Cretaceous time.

A similar westerly trending scarp occurs a mile or two north of the lake, extending from Meade Creek as far west as Youbou Creek. Of somewhat similar origin are the northwesterly trending valleys of the west fork of Cottonwood Creek, South Nanaimo River, and Rift Creek, all of which follow post-Upper Cretaceous fault zones. As most of the movement on the faults is probably in a vertical direction, one or other wall of these valleys represents a post-Cretaceous fault scarp, highly modified by erosion.

GLACIATION

Several features of the Cowichan Lake area indicate that the continental ice-sheet covered the entire region. Even the highest peaks are well rounded, and glacial erratics have been noted as high as 4,700 feet above sea-level. Striæ on tops of ridges are not well preserved, but on the ridge east of Mount Service, striæ trend south to south 15 degrees west, and at an elevation of 4,500 feet on the ridge at the head of the southwest fork of Nitinat River, striæ trend south 10 to 15 degrees east. Stoss and lee surfaces indicate that the ice moved southward.

Valleys show evidence of valley glaciation. Cirques and cirque lakes, such as Lomas Lake, Sherk Lake, and Delphi Lake, are common. U-shaped valleys and glacial grooves on valley walls are numerous. Two shallow abandoned melt-water channels were noted along the east side of Shaw Creek.

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CHAPTER II.—GENERAL GEOLOGY

SUMMARY OF GENERAL GEOLOGY

The Cowichan Lake area is underlain mainly by late Palæozoic and Mesozoic volcanic, sedimentary, and granitic rocks. They fall into three divisions—pre-granitic crystalline Palæozoic and Triassic rocks of the Sicker and Vancouver groups, granitic rocks comprising the Saanich granodiorite, and Upper Cretaceous detrital sediments of the Nanaimo group.

The Palæozoic rocks, known as the Sicker group, are dominantly sediments which are partly of volcanic origin. They include distinctive thin-bedded cherty, argillaceous and feldspathic tuffs, limestone, coarse and fine breccias, and greenstones. Amygdaloidal basalt flows are intercalated with the sediments and at places form the predominant rock type. Along strike the rocks appear to change facies rapidly, and continuous markers or uniform stratigraphic sequences within the Sicker group have been determined only for relatively small areas. At the top of the group, crinoidal limestone and calcareous sediments contain Lower Permian fossils.

TABLE OF FORMATIONS

Era	Period	Name		Lithology
Cenozoic.	Tertiary(?).			Gabbro.
	Relationship not known.			
	Upper Cretaceous.	Nanaimo group.	Haslam formation.	Black marine shale and brown sandstone.
			Benson formation.	Conglomerate.
	Unconformity.			
Mesozoic.	Jurassic(?) or Lower Cretaceous(?).	Saanich granodiorite.		Mainly granodiorite and quartz diorite.
	Intrusive contact.			
	Upper Triassic.	Vancouver group.		Clastic sediments.
			Sutton limestone.	Grey fine-grained limestone.
	Triassic and (or) Permian.		Franklin Creek volcanics.	Basalt flows and related intrusions of diabase.
Palæozoic.	Conformity or disconformity.			
	Permian and older.	Sicker group.		Limestone and minor chert. Cherty tuffs, fine-grained clastic sediments, breccias, and basaltic flows.

The Sicker group is conformably or disconformably overlain by rocks of the Vancouver group. The Franklin Creek volcanics form the lower part of the Vancouver group, and consist of massive and pillow basalt flows, and related sills, dykes, and irregular masses. The flows possibly total as much as 10,000 feet thick, and at places toward the top of the section contain lenses of dense grey limestone.

The Sutton limestone contains Upper Triassic fossils and overlies the Franklin Creek volcanics conformably. It consists of lenses of grey limestone which grade along strike into thin-bedded, fine-grained clastic sediments. A sequence of clastic sediments partly of volcanic origin also overlies the Sutton limestone, but only part of this sequence is exposed within the area. The Sutton limestone and overlying sediments comprise the upper part of the Vancouver group.

The Palæozoic and Triassic rocks are highly deformed into northwesterly trending folds, many of which are overturned, with both limbs dipping southwestward.

Rocks of the Sicker and Vancouver groups are cut by granitic masses belonging to the Coast intrusions and ranging in composition from quartz diorite to aplogranite. These plutonic rocks are the Saanich granodiorite. Most of the granodiorite forms steeply dipping elongated masses, some of which are more than 20 miles long and no more than 2 miles wide.

Detrital sediments of the Nanaimo group unconformably overlie the granodiorite and the older volcanic and sedimentary rocks. Basal conglomerate, the Benson formation, is overlain by brown sandstone and black shale of the Haslam formation. These rocks are correlated on lithological and fossil evidence with Upper Cretaceous rocks on the east coast of Vancouver Island. They have been moderately folded along westerly trending axes and are cut by steeply dipping faults. The faults strike between west and northwest, and on several of them the displacement is more than 1,000 feet and is largely vertical.

A few small bodies of gabbro intrude rocks of the Sicker group and the granodiorite near the east edge of the Cowichan Lake area. They are thought to be Tertiary in age because they intrude the granodiorite and are lithologically similar to Eocene intrusive rocks near Sooke, about 50 miles south of Cowichan Lake.

PRE-GRANITIC ROCKS

Pre-granitic rocks in the Cowichan Lake area include a thick sequence of volcanics and sediments with very few continuous markers. During his early reconnaissance of southern Vancouver Island, Clapp discovered fossils in a limestone lens in this sequence exposed on the south shore of Cowichan Lake (Clapp, 1912, p. 68). The fossils at that time were considered to be Lower Jurassic, but were assigned subsequently to the Upper Triassic (Shimer, 1926, p. 88). No other fossils were found in mapping the Sooke and Duncan areas, and as a result all the limestone in that area was considered by Clapp to be of the same age, and all rocks associated with limestone were included in the Triassic and Jurassic, Vancouver group (Clapp and Cooke, 1917, p. 93). The Sicker series was included in this group, although its true relations to the Vancouver volcanics and Sutton limestone were uncertain. Later work on San Juan Islands (McLellan, 1927), in the Buttle Lake area (Gunning, 1930), in the Bedwell River area (Sargent, 1941), and in the China Creek area (Stevenson, 1944), as well as the early discovery of Carboniferous or Permian fossils in limestone at Horne Lake (Richardson, 1873), indicated that Palæozoic limestone is widely distributed on southern Vancouver Island and vicinity, and suggested that part of the limestone mapped as the Sutton formation by Clapp might be Palæozoic.

During the course of mapping in the Cowichan Lake area it was found that much of the limestone exposed in the area is lithologically different from that at the Sutton type locality on the south shore of the lake. Two types of limestone were distinguished in the field: one is commonly crinoidal and contains Lower Permian fossils, and the other is very similar to the Sutton limestone at the type locality. The Permian limestone is overlain by massive or pillow basalt, termed the Franklin Creek volcanics, and is associated with sediments continuous with or similar to the Sicker sediments of the Duncan area. Consequently, the crinoidal limestone and sediments have been mapped as the Sicker group and are considered to be Lower Permian and older. The Vancouver group overlies the Sicker group, and has been subdivided into (1) the lower, Franklin Creek volcanics, and (2) the upper, Sutton limestone and related sediments. The Sutton limestone is overlain by and grades laterally into clastic sediments. The clastic sediments outcrop mainly beyond the limits of the area mapped and have not been studied in detail.

Sicker Group

Rocks of the Sicker group underlie about two-thirds of the Cowichan Lake area. The group includes a wide variety of volcanic and sedimentary rocks thought to be Lower Permian and older. Lithologic types show a marked discontinuity along the strike. In short distances, lenses of thin-bedded sediments give place to massive sediments, breccias, or flows. Many of the clastic sediments display no bedding, and the flows are massive or amygdaloidal. The lens-like character of some of the rocks and the massive nature of others make it impossible to establish a stratigraphic column that is generally applicable. The following rock types are present in the Cowichan Lake area, and the general assemblage may be recognized widely on southern Vancouver Island.

Amygdaloidal Rocks.—Amygdaloidal rocks of the Sicker group predominate in the northwestern part of the area. They are exposed in the area around the headwaters of Nitinat River on Mount Hooper and the ridges at the head of Sadie Creek. Throughout the Cowichan Lake area, however, amygdaloidal rocks are interbedded with pyroclastic breccias and sediments. Where amygdaloidal rocks predominate, they have been mapped as a unit (*1a* of Fig. 2).

On fresh surfaces, the amygdaloidal rocks are light green, grey-green, or, less commonly, purplish. Weathered surfaces are dark grey, green, and, rarely, purplish or brown. Both aphanitic and porphyritic varieties are common. Mafic phenocrysts 1 to 3 millimetres across are distinguishable in hand specimens, and smaller plagioclase phenocrysts can be seen in thin section.

Amygdules are common in the greenish varieties and abundant in the purplish varieties, but apart from amygdules primary structures are scarce. The amygdules are generally less than 5 millimetres in diameter, and composed of chlorite, quartz, calcite, and epidote. The purplish scoriaceous types are regarded as flows. Most of the other amygdaloidal rocks are also considered to be flows, but definite evidence of their origin has not been found.

Pillow structures are rare in rocks of the Sicker group. Pillows were noted at an elevation of 1,750 feet on the north side of the east fork of Shaw Creek, and at an elevation of 1,900 feet on the westward-flowing tributary of Nitinat River near the north edge of the map (*see* Fig. 2). At each place the pillows are 2 to 4 feet in diameter and composed of grey-green volcanic rock essentially the same as that of the more massive flows. Most of the pillows are structureless, but at the Shaw Creek locality concentric layers rich in amygdules alternate with layers containing few amygdules. Pillow contacts are marked by a light-green amygdaloidal rim, rich in epidote, and spaces between three contiguous pillows are filled with red jasper.

Light-green streaks rich in fine-grained epidote are common in some of the more massive volcanics. They are discontinuous, irregular in form, and are generally a few inches wide and a few feet long. In some respects they resemble the light-green layers associated with pillows. Lenses and masses of jasper occur in the amygdaloidal rocks particularly near the northwest end of the area. The jasper is brick red, massive, and composed of microcrystalline quartz and finely divided hematite. The masses are irregular and range in length and thickness from a few inches to several feet.

Porphyritic amygdaloidal rocks are seen in thin section to be made up of subhedral pyroxene and plagioclase phenocrysts in an aphanitic groundmass of the same two minerals. Except in the northwestern part of the area, the rocks are altered so that the composition of the plagioclase and groundmass is difficult to determine. Hornblende is the most abundant alteration product, and small amounts of chlorite, epidote, biotite, sericite, and leucoxene are widely distributed. Magnetite and sphene are common accessories. Plagioclase phenocrysts in the least altered specimens appear to be andesine or labradorite. The pyroxene is augite, and rhombic pyroxene is lacking. The rocks are estimated to have been composed originally of about 50 per cent pyroxene and 50 per cent plagioclase. A chemical analysis of one of the least altered amygdaloidal rocks of the Sicker group is given in the table on page 40 (No. 5349). The specimen analysed contains a considerable amount of secondary hornblende but is basaltic in chemical composition.

Breccias and Massive Sediments.—Breccias and massive tuffaceous greywackes make up a large part of the Sicker group. They have been mapped as a unit (1*b* of Fig. 2) largely because they lack bedding and hence contrast markedly with other sediments of the Sicker group in which bedding is conspicuous.

The breccias and tuffaceous greywackes are green or grey and composed of crystal and rock fragments ranging from a tenth of a millimetre to as much as a foot across. Rocks consisting entirely of the finer sizes (0.1 to 1 millimetre) are generally massive and often indistinguishable from flow rocks. The fine-grained rocks may contain widely scattered fragments several inches across, and every gradation exists between rocks containing a few coarse fragments and those made up almost entirely of coarse fragments. The coarser varieties commonly have a matrix of finer clastic sediments, but in some the finer material is absent. On weathered surfaces, coarse breccias containing little fine material commonly have irregular cavities between the fragments. The rocks appear to have been cemented by materials that have been weathered away or to have been lithified with very little cementing material.

Both coarse and fine fragments are mainly of porphyritic basalt and fine-grained clastic and cherty sediments that appear to have been derived from the surrounding and underlying rocks. Broken crystals of hornblende and rarely of pyroxene can be seen in hand specimens and in thin sections of some of the finer sediments. Devitrified shards were noted in one thin section. The fragments are set in a matrix of siliceous, calcareous, or, more commonly, argillaceous material more or less altered to very fine epidote, flakes of biotite, or needles of hornblende.

The breccias and massive tuffaceous greywackes are of mixed volcanic and detrital origin. They probably include products of direct volcanic activity, water-lain pyroclastic material, and non-pyroclastic detrital sediment. Broken crystals of amphibole and pyroxene in these rocks are of pyroclastic origin. Very angular grains and large fragments in essentially fine-grained rocks are also probably pyroclastic. Most fragments, however, are of uncertain origin.

Thin-bedded Non-calcareous Sediments.—Toward the eastern edge of the map-area, the Sicker group is made up mainly of thin-bedded sediments. Elsewhere lenses of similar sediments are interbedded with flows and breccias. The thin-bedded sediments are largely cherty and feldspathic tuffs, tuffaceous greywackes, and minor breccias. In general the sediments are blocky, but they are schistose where interbedded with massive volcanics and along fault zones.

The cherty tuffs are dominantly cream coloured, black, green, or brick red. Weathered surfaces are whiter than fresh surfaces. Alternating bands a quarter of an inch to 4 inches thick of two of these colours or light and dark shades of any one of them give the rocks a striped appearance (*see* Plate V). Individual beds either grade imperceptibly into one another or are sharply defined. Sharp contacts between beds commonly show local disconformities, but primary structures of this type have generally been obscured by contortions and small-scale faulting across and parallel to the bedding. The cherty tuffs have a porcelainous texture, breaking with a blocky or conchoidal fracture. In most outcrops a well-defined set of joints parallels the bedding.

Microscopic examination reveals that whitish beds are rich in angular plagioclase crystals, some of which have been identified as calcic andesine (*see* Plate VII). The darker beds are composed of chert with varying amounts of epidote, chlorite, and hornblende or hematite occurring as laminæ parallel to the bedding or as grains disseminated throughout the chert. The chert is microcrystalline quartz. Mafic silicates and hematite are less than 0.02 millimetre across, whereas plagioclase crystals may be as much as 0.3 millimetre across. Chert and plagioclase crystals vary widely in proportion so that the rocks range from almost pure chert to feldspathic crystal tuff.

Under the microscope and on smooth faces of hand specimens spherical nodules as much as 0.3 millimetre in diameter can be seen in the more cherty tuffs (*see* Plate VII). Thin sections show that the nodules are composed of fine-grained quartz, coarser grained than that of the surrounding chert. Fine epidote and carbonaceous matter outline both the nodules and a vague radial internal structure near the edges of a few of them. Bedding planes, which in thin section appear as laminæ rich in epidote or carbonaceous matter, bulge around the nodules, and none was seen passing through them. The nodules are surrounded by microcrystalline quartz and are rarely in contact with one another.

They are thought to be of organic origin mainly because of the fact that the rocks closely resemble radiolarian cherts from other localities. However, there is no direct evidence that the nodules in cherts of the Sicker group are radiolaria. Only spherical shapes have been seen, and more complex shapes, if they ever existed, appear to have been obliterated. The nodules do not resemble siliceous oolites because they generally are widely spaced and contain no central nucleus; nor do they resemble spherulites for they are well formed and do not penetrate one another.

The rocks are termed cherty tuffs because they are made up of chert and tuffaceous material. The composition and fragmental character of the plagioclase indicate that it is of pyroclastic origin. No features of the rocks point conclusively to the origin of the chert. Nevertheless, the following facts support the belief that silica was deposited along with the sediments and was not derived from later processes of silicification. Volcanic rocks associated with the cherty tuffs are not silicified, and limestone is only slightly silicified. Beds of chert in limestone that probably are of replacement origin are mottled and poorly bedded, and differ from the well-bedded cherty tuffs. Breccias, near the head of Meade Creek, overlie cherty tuffs in that area and are probably stratigraphically above most of the cherty tuffs of the Sicker group. In addition to volcanic rock and crystal fragments, the breccias contain angular pieces of cherty tuff identical with that of the older members of the Sicker group. The breccias are not silicified, and hence the silica in the cherty tuffs appears to have formed before deposition of the Sicker group was complete.

Thus it is concluded that the silica is syngenetic or diagenetic, but no definite conclusion is reached regarding its precipitation. If the spherical nodules in the cherty tuffs are radiolaria, part of the silica has been precipitated by organic means. Spherical nodules, however, comprise only a small proportion of the chert in the tuffs, and no evidence has been found to show by what method the remainder of the silica was deposited.

Crystal tuffs overlie the cherty tuffs in the eastern part of the area and occur locally with other thin-bedded sediments elsewhere in the Sicker group. The crystal tuffs are grey to black on fresh surfaces and whitish on weathered surfaces. The beds range from half an inch to 4 inches thick, with 2- to 4-inch beds most common.

In thin section these rocks are seen to be made up largely of plagioclase and biotite and contain minor amounts of sericite, chlorite, and epidote. Plagioclase occurs as angular and subangular grains 0.05 to 0.3 millimetre across, surrounded and in part replaced by fine flakes of dark-brown biotite. The plagioclase is twinned, very slightly zoned, and where identifiable is either calcic andesine or labradorite. A certain amount of sorting of plagioclase has given rise to poor bedding. Biotite is more abundant in the finer material, and this accentuates differences in colour between beds.

The plagioclase is pyroclastic, but the biotite and other silicates appear secondary and have resulted from the alteration of volcanic dust or argillaceous material. Locally the presence in the crystal tuffs of rounded grains of quartz apparently of detrital origin and the close association with cherty rocks and with limestone suggest that the crystal tuffs have been deposited in sea water.

Massive breccias and tuffaceous greywackes are locally intercalated with feldspathic and cherty tuffs of the Sicker group. The massive rocks are similar to those described previously (*see* p. 14) but form beds a few feet to a few tens of feet thick in the sequence of thin-bedded sediments. Many of the tuffaceous greywackes have beds a few inches thick. They are similar in composition to the massive greywackes, but sorting of the fragments has produced bedding and locally has resulted in graded bedding.

In Shaw Creek, near the north end of the logging grade, several outcrops expose 30 to 40 feet of conglomerate made up of rounded fragments of purplish amygdaloidal volcanic rock in a finer matrix of the same material. The largest fragments are about 10 inches in diameter and are sorted into layers which give the rock a poor stratification. The fragments are of detrital origin either well worn pyroclastic fragments or products of subaqueous erosion and deposition.

Limestone.—Lenses of limestone thought to belong to the uppermost formation of the Sicker group outcrop at several localities. Thickest sections are exposed on the peninsula at the east end of Cowichan Lake, on the south side of Cowichan Valley south of Lake Cowichan, and in the upper part of Rift Creek. Thinner lenses occur on the west slope of Mount Landalt at an elevation of about 3,800 feet and extend west at about the same elevation along the southwest face of Mount Service to the head of Cottonwood Creek. Lenses of limestone containing many fragments of volcanic rock outcrop on the southeast slope of Mount Franklin between elevations of 2,700 and 3,000 feet and on the ridge between Shaw Creek and its west fork at about 3,000 feet elevation almost due west of the end of the logging grade in Shaw Creek.

The limestone is white and grey, weathers buff or blue grey, and has a fine- to medium-grained texture. Although bedding is obscure in the purest varieties,* partings of chloritic material, beds of chert, or fragments of volcanic rock are common, and hence the rocks are generally well bedded. The thickness of individual beds ranges from less than an inch to several feet.

Much of the limestone is crinoidal. Fragments of stems range from single disks to sections several inches long and from one-eighth of an inch to almost an inch in diameter. A few of these stems are brick red and silicified, but most are coarsely crystalline calcite. Many outcrops appear to contain only sparse recognizable crinoid stems, but the limestone has a characteristic granular crystalline texture that distinguishes it from the Sutton limestone.

Limestone, chert, and tuffaceous sediments of the Sicker group outcrop on the south side of Cowichan Valley south of Lake Cowichan for about 3 miles along the strike of the formation. To the northwest the sediments are covered by Cretaceous rocks, and to the east they are displaced by a fault which strikes northward. East of the fault, limestone of the same formation extends into the Duncan area (Clapp and Cooke, 1917, map 42*a*). West of the fault, the limestone is underlain by breccias and massive greenstones and overlain by the Franklin Creek volcanics. The calcareous sequence is mainly grey crinoidal limestone with minor amounts of black chert. Beds range from a few inches in the more cherty sections to 30 or 40 feet thick in the purer limestone sections. Many of the thinner-bedded rocks show graded bedding. Beds 1 to 4 inches thick are made up of two parts—a lower of grey relatively coarse calcareous material grading into an upper of black fine-grained siliceous material (*see* Plate VIII). The alternation of siliceous and calcareous layers can be seen in the outcrops, and commonly as many as a dozen beds show the repetition of coarse calcareous material to fine siliceous material in the same direction. In thin section the rocks are seen to consist almost entirely of fragments of organisms such as crinoid stems and sponge spicules. Although the coarse material is largely calcareous and the fine siliceous; coarse siliceous fragments are locally present in the calcareous layer and fine calcareous fragments are present in the siliceous layer. Hence the graded bedding appears to have been controlled by mechanical processes depending on the size of the fragments, and not on biological processes involving changes

* Spectrochemical analyses show that typical limestone with no visible impurities may contain several per cent magnesium.

in the dominant form of life with time. Therefore, it has been assumed that the coarse calcareous part of each bed was originally laid down below the siliceous part.

The beds in the exposures along the south side of Cowichan Valley dip southwest at angles ranging from 30 to 70 degrees. Details of the structure are complex. Graded bedding along the southwest side of the exposures indicates that the beds dip and face southwest. Hence the basalt that outcrops on the crest of the ridge to the southwest overlies stratigraphically the limestone-chert sequence. The beds form either a simple monocline or a tightly folded structure made up of an overturned anticline on the southwest and a syncline on the northeast. The structure of the limestone-chert sequence south of the North Arm of Cowichan Lake and the possible repetition of some of the beds suggest that the tightly folded structure is the more probable. On the basis of this structure the beds are estimated to be 500 to 1,000 feet thick.

Limestone of the Sicker group outcrops on the peninsula at the east end of Cowichan Lake essentially along the strike of the limestone on the south side of Cowichan Valley, but separated from it by the drift-covered area of Cowichan Valley and by Cowichan Lake. The sequence at this locality includes grey crinoidal limestone, green, pink, and black chert, clastic sediments, and breccias. The limestone locally contains poorly preserved brachiopods. The clastic sediments and breccias outcrop on the east end and north side of the promontory. They are overlain by and grade laterally into limestone and chert. The limestone and chert in turn are in contact on the southwest with the Franklin Creek volcanics. Black, green, and pink chert form a discontinuous band as much as 40 feet thick near the contact with the volcanics. The beds in general dip southwest, forming overturned folds, anticlinal on the southwest and synclinal on the northeast. An estimated 800 feet of limestone and chert is exposed. Diabase of the Franklin Creek volcanics intrudes the limestone for a distance of half to three-quarters of a mile west of Marble Bay, but farther to the west basalt of the same formation conformably overlies the limestone.

Relatively flat-lying beds of the Sicker group outcrop along the west slope of Mount Landalt and on the south side of Mount Service. Locally they contain lenses of limestone which have been correlated with those on Cowichan Lake and on the south side of Cowichan Valley. The limestone outcrops at an elevation of about 2,700 feet and is best exposed in a precipitous canyon on the west side of Mount Landalt. At this locality 30 to 40 feet of greyish-white crinoidal limestone outcrops for a distance along the hillside of several thousand feet. The limestone overlies black rusty-weathering cherty tuff, and grades laterally into calcareous green sediments. It is overlain by 100 to 200 feet of basaltic flows and sill-like intrusions which are separated from the main part of the Franklin Creek volcanics on the upper slopes of Mount Landalt by 30 to 40 feet of cherty sediments. Some of the crinoid stems in the limestone are brick red and silicified. Fragments of deformed shells were found in the calcareous green sediments. They are poorly preserved but resemble the brachiopods on the peninsula at the east end of Cowichan Lake.

Limestone, chert, and tuffaceous sediments outcrop on the southwest side of Rift Creek to elevations of 2,000 feet. They form the lower precipitous slopes of the ridge southwest of the creek. The area underlain by the sediments is bounded on the east by a fault and in other directions by Franklin Creek basalt which is believed to overlie the limestone. The stratigraphic sequence and the lithology of the sediments at this locality are the same as those south of Lake Cowichan and on the peninsula at the east end of Cowichan Lake. Although the localities are many miles apart, there is no doubt that the sediments belong to the same formation. In the Rift Creek section crinoidal limestone grades along strike into black, green, and brick-red chert and cherty tuff, with which it is also interbedded. Toward the southeast it grades into fine-grained green sediments. Crinoid stems are numerous in the limestone, and fragments of corals and brachiopods occur locally. The rocks are highly contorted, but in general dip southwestward. They are estimated to be about 1,000 feet thick.

Stratigraphic Sequence within the Sicker Group.—The stratigraphic succession within the Sicker group is not well known and varies from place to place. The following table summarizes the sequence near the east and west ends of Cowichan Lake, the two most widely separated localities where a recognizable marker provides a basis for correlation.

STRATIGRAPHIC SEQUENCE WITHIN THE SICKER GROUP

Meade Creek (Composite Section)		West Fork of Shaw Creek	
Approximate Thickness (Feet)	Rock Type	Approximate Thickness (Feet)	Rock Type
	Top not exposed.		Top not exposed.
		200–300	Purplish volcanic breccia.
		1,300	Green tuffaceous greywackes.
		250	Amygdaloidal basalt.
2,000	Grey to black feldspathic tuffs and argillaceous sediments, minor breccias.	1,000	Thin and thick beds of tuffaceous greywacke.
		800	Black feldspathic and argillaceous tuffs, thin limestone lenses.
600	Thin-bedded cherty tuffs, minor feldspathic tuffs and tuffaceous greywackes.	600	Thin-bedded cherty tuffs.
1,500–2,000(?)	Green volcanics (massive sediments, breccias and flows).	4,500	Massive green clastic sediments and breccias.
500	Thin-bedded cherty and tuffaceous greywackes.		
3,000–4,000	Mainly massive green volcanics.		
Base unknown.		Base unknown.	

Thicknesses in the Meade Creek section are based on interpretation of the structure of relatively massive volcanics and of complexly folded sediments, and are but estimates. The Shaw Creek section was measured on the south and north sides of the west fork of Shaw Creek about 5½ miles northwest of its junction with Shaw Creek.

The 600-foot sequence of thin-bedded cherty tuffs shown in both columns of the table overlies a distinctive coarse breccia a few tens of feet thick. The cherty sediments are typically well banded, grey, green, or brick red, and the breccia consists of fragments of amygdaloidal volcanic rock 1 inch to several inches across in a fine-grained matrix (*see* Plate IX). The breccia-cherty tuff sequence is a marker that has been traced from Meade Creek to Widow Creek and recognized again in Shaw Creek.

The rocks immediately above the marker show only minor changes between Meade Creek and Shaw Creek, but to the north the lithology appears to change rapidly. The transition is best exposed in Shaw Creek where the structure is relatively simple. Thin-bedded, dominantly cherty tuffs grade northward into green thick-bedded tuffaceous greywackes that, farther north, grade into massive greenstones, dominantly sediments, with minor flows. The gradation, which is complex in detail, takes place over a distance of several miles, and is most pronounced in the thousand feet of beds immediately above the marker.

A similar change is thought to occur north of the head of Jump Creek and along the head of Chemainus River. Complicated structures in these areas obscure the evidence for sedimentary lensing, but, if the changes do exist, they indicate a local coarsening of the cherty and feldspathic sediments to the north and west between Shaw Creek and Mount Whymper.

Age and Correlation.—The term " Sicker series " was originally used by C. H. Clapp (1912, p. 71) to describe a series of mainly schistose sedimentary, volcanic, and intrusive rocks occurring on Mount Sicker in the Duncan area. In the Sooke and Duncan Memoir (Clapp and Cooke, 1917) the intrusive rocks were distinguished from other rocks of the Sicker series as the Sicker gabbro-diorite porphyrite. Work by H. C. Cooke showed that not all the rocks of the Sicker series are schistose, and that the sediments in general conformably overlie the volcanics. The series was considered to belong to the Vancouver group but no fossils were found in it, and the exact relation of the series to other members of the Vancouver group was uncertain (Clapp and Cooke, 1917, p. 152).

Rocks of the Sicker group,* both volcanics and sediments, have been traced westward from the Duncan area into the Cowichan Lake area. For several miles west of the Duncan area the sequence is essentially the same as that described by Cooke, the Sicker volcanics corresponding to rocks below the marker of page 18, the Sicker sediments to those above. On the western slopes of Mount Landalt the sediments contain lenses of limestone overlain by massive basalt (*see* p. 17) and lithologically similar to limestone on the peninsula at the east end of Cowichan Lake, which is also overlain by basalt. The limestone on the peninsula contains fossils. Some were collected 1½ miles northwest of Marble Bay on the top of the main ridge of the peninsula, at an elevation of about 1,000 feet from beds between 200 and 400 feet below the base of the Franklin Creek basalt. Poorly preserved brachiopod fragments from this collection identified by Peter Harker, of the Geological Survey of Canada, include:—

Productus cf. *P. uralicus* Tschern.
Productus cf. *P. weypirchti* Toula.
Spiriferella saranæ var. *arctica* Houghton.

According to Harker, "The fossils identified indicate a lower Permian age for the beds. *S. saranæ* var. *arctica* is especially characteristic. It occurs in the Cache Creek series of central B.C. and has also been reported from the Yukon."

Specimens of crinoidal limestone from this locality and from the limestone on the south side of Cowichan Valley have been studied by M. L. Thompson, of the University of Wisconsin. He reports that they contain fusulinids, and that the sample from the peninsula contains "what seems to be a *Schwagerina* of general Permian Wolfcampian aspects," and that from south of Lake Cowichan "contains a *Quasifusulina*." Palæontological evidence, therefore, indicates a lower Permian age for the limestone on the peninsula and probably also for the limestone south of Lake Cowichan.

The limestone on Mount Landalt contains no index fossils but is lithologically very similar to that on the peninsula. The rocks underlying the limestone on the peninsula are poorly bedded sediments and massive greenstones. They differ from the thin-bedded tuffs and green sediments beneath the limestone on Mount Landalt. However, the similarities between the limestone-basalt sequence on the peninsula and on Mount Landalt, and the occurrence of a similar limestone-basalt sequence on the south side of Cowichan Valley, southwest of Rift Creek, and at other places on Vancouver Island (Sargent, 1941, p. 17; Mathews, 1947, p. 48; Gunning, 1930, p. 61A) have led the writer to believe that the limestone-basalt contact is at about the same horizon throughout the Cowichan Lake area and possibly over a larger area. If this assumption is correct, rocks of the Sicker group are Permian and older. The term "Sicker group" has been used in this report to include volcanic and sedimentary rocks that are lithologically similar to or associated with rocks like those of the Sicker series of the Duncan area. The top of the limestone is considered to be the base of the Vancouver group.

Vancouver Group

The Vancouver group, originally referred to as the Vancouver series, was named by G. M. Dawson (1887) from his study of the rocks of northern Vancouver Island. Although he was unable at that time to differentiate Triassic from Carboniferous rocks, he suggested that the term "Vancouver series" be used for Triassic volcanic and sedi-

* The older term "series" has been replaced by "group" because the Sicker (as well as the Vancouver and Nanaimo groups) are regarded as rock units and have no time significance.

mentary rocks. Since then Triassic and Carboniferous rocks have been differentiated and subdivided, and Triassic rocks on Vancouver Island have been referred to the Vancouver group. The relationship of the Triassic and possibly Lower Jurassic rocks on Texada Island and the mainland coast of British Columbia to those known on Vancouver Island as the Vancouver group has been discussed by Mathews (1947, p. 35).

In this report the term "Vancouver group" is used in approximately its original sense to include the Sutton limestone, known to be Upper Triassic, clastic sediments which overlie the Sutton limestone, and the Franklin Creek volcanics which underlie the Sutton limestone and overlie the Lower Permian limestone of the Sicker group.

Probably complete sections of the Franklin Creek volcanics are exposed in the Cowichan Lake area. Sediments younger than the Sutton limestone extend beyond the limit of the present map, and knowledge of complete sections of the Vancouver group in this area must await more extensive geological work, particularly to the southwest.

Franklin Creek Volcanics.—The term "Franklin Creek basalt" was introduced by Stevenson (1944) to describe basaltic rocks in the China Creek area which are structurally continuous with similar rocks in the Cowichan Lake area. The term has therefore been retained, but extended to include both basalt and diabase thought to be extrusive and intrusive parts respectively of one volcanic formation. The Franklin Creek volcanics overlie and intrude rocks of the Sicker group. They form the rugged summits of Mount Whymper and El Capitan as well as the bluffs at the east end of Cowichan Lake and southwest of Rift Creek. In the northeast corner of the Cowichan Lake area the Franklin Creek volcanics all appear to be intrusive. On Mount Service, Mount Landalt, and the peninsula at the east end of Cowichan Lake, both intrusive and extrusive rocks occur, and northwest of the west end of Cowichan Lake only extrusive varieties were recognized.

The extrusive rocks are dark green to black, fine-grained and aphanitic rocks which characteristically weather brown. Locally they are porphyritic with phenocrysts of plagioclase and pyroxene a few millimetres across. Principal constituents of the Franklin Creek basalts, recognized in thin sections, are labradorite and augite. Magnetite and sphene are the main accessories, and hornblende, chlorite, and epidote are common alteration products. Modal analyses (*see* table, p. 21) indicate that before alteration the rocks contained about equal amounts of plagioclase and pyroxene.

Pillow structure and amygdules are common. These structures, particularly the pillows and the brown colour of weathered surfaces, serve to distinguish the Franklin Creek basalt from flows and massive volcanics of the Sicker group. The pillows are roughly ellipsoidal and range from about 10 inches to 3 feet in longest dimension (*see* Plate X). They are generally massive internally, but a few exhibit a central mass of amygdaloidal rock a few inches in diameter. Individual pillows are outlined by a dark-green amphibole-rich band as much as an inch thick. Inter-pillow spaces contain white quartz, amphibole, and locally prehnite. Pillow lavas appear to be finer grained than the amygdaloids, some are very dense, and may in part be devitrified glass. Amygdules averaging about one-quarter of an inch in diameter are locally abundant and are particularly well displayed on the ridge northwest of Gordon Bay near the south edge of the Cretaceous sediments and at the west end of Cowichan Lake. They consist of quartz, epidote, chlorite, and calcite, and commonly stand up in relief on weathered surfaces.

Intrusive bodies of Franklin Creek volcanics are found as sills, dykes, and irregular masses in rocks of the Sicker group. They are most abundant in the eastern half of the area, and northeast of Chemainus River are the only members of the Franklin Creek volcanics exposed. The intrusive rocks have the same composition and appearance as the extrusive, but lack the pillows and amygdules which are characteristic of the flows. They are aphanitic to medium grained and differ from the Tertiary gabbros, which are commonly coarse grained. Some are porphyritic with phenocrysts of white-weathering plagioclase locally occurring in clusters.

Centres of larger sills and dykes are fine to medium grained, and edges within a foot of contacts are aphanitic. Thin sections of the fine- and medium-grained rocks exhibit a subophitic texture. Slightly zoned laths of labradorite penetrate more equidimensional crystals of augite. Augite is more or less altered to pale-green hornblende, and laths of plagioclase commonly contain minute crystals of an epidote mineral resembling clinozoisite. Magnetite and sphene are common accessories. Leucoxene and chlorite occur in some thin sections. Mineralogical analyses (*see* following table) indicate an original composition of about 50 per cent plagioclase and 50 per cent pyroxene.

APPROXIMATE MINERALOGICAL COMPOSITION OF THE FRANKLIN CREEK VOLCANICS (VOLUME PER CENT)

Specimen No.	Plagioclase	Pyroxene[1]	Hornblende	Chlorite	Epidote	Clinozoisite	Accessories[2]
Diabase							
535	50	26	13	8	0.5	—	2.5
229	39	8	42	+	—	8	3
230	47	31	13	+	—	5	4
310	62	14	16	4	—	2	2
393	63	6	26	+	—	—	5
Basalt							
479	55	35	—	5	2	—	3
358	37	31	—	18	14	—	1
336	41	35	—	8	10	—	6
133	23	26	51	+	—	+	1

[1] Augite.
[2] Mainly magnetite, minor sphene.
+ Present. — Absent.

Localities

535—Half a mile west of Marble Bay.
229—Sill 1 mile west of Rheinhart Lake.
230—Sill 1 mile west of Rheinhart Lake.
310—Sill-like mass, crest of ridge half a mile northwest of the top of Mount Whymper.
393—Near Saanich granodiorite 2 miles northeast of the top of Mount Whymper.
479—Crest of ridge 2 miles southeast of the top of Mount Spencer.
358—Northwest slope of Blue Grouse Hill.
336—Half a mile north of the west end of Cowichan Lake.
133—Half a mile southeast of the top of El Capitan.

Intrusions of diabase in bedded sediments of the Sicker group commonly are sills. They are well displayed between Mount Whymper and Rheinhart Lake, where sills extend eastward as tongues from a large intrusive mass north of Mount Whymper. The shape of this large mass is uncertain, but where the contact is exposed on the southwest slopes of Mount Whymper, it appears to be concordant with sediments of the Sicker group. The sediments dip northward, and the contact may be the upturned base of a very thick sill, or possibly a laccolith. North of Mount Whymper, blocks of cherty tuff 50 to 100 feet across and smaller masses of chert breccia are enclosed in the large intrusive mass. The chert breccia consists of angular fragments of cherty tuff as much as an inch across surrounded by basalt. The sediments in the large blocks and in the breccia are similar to cherty tuff of the Sicker group, and appear to form remnants of partings that occur between sills to the east. The sills extend eastward from the large mass north of Mount Whymper as subparallel sheets. At least four continuous sills, each about 1,000 feet thick, and several thinner ones have been traced as far east as Rheinhart Creek. The sediments between the sills are locally schistose and crumpled, and although most contacts are concordant, at places the diabase cuts across the bedding in such a way that the sedimentary partings gradually thicken to the east.

Southeast of Rheinhart Lake the sill-like character of the diabase is less common than to the west, and dykes and irregular masses are more abundant. Northeast and east of South Nanaimo River as far east as Haslam Creek the intrusive rocks are largely sills dipping gently north similar to those west of Rheinhart Creek. To the south in a triangular-shaped area with apex at Rheinhart Lake and base along the east edge of the map (*see* Fig. 2) extending 2 miles south from the head of the south fork of Haslam

Creek, both sediments and intrusive rocks are schistose. The complex deformation of the schistose rocks has left the diabase as lenses of chlorite schist and schistose diabase in a quartz-schist sequence. Intrusive bodies tend to be massive in the centre and schistose on the edges. The area of schistose rocks narrows to the west into what is probably a fault followed by the course of South Nanaimo River.

South of Chemainus River the diabase is very fine grained and locally porphyritic. The Sicker sediments exposed between Chemainus River and the fault that extends from Mount Franklin to the head of Cottonwood Creek have relatively gentle dips. They are overlain or intruded by concordant masses of diabase totalling as much as 2,000 feet thick. The basal members of this mass, exposed on the lower slopes of the east side of Mount Landalt, intrude the sediments as sills. Diabase higher on Mount Landalt, as well as on most of El Capitan, Mount Service, and Mount Franklin, exhibits no primary structures and is considered to be intrusive. On the cliffs on each side of the cirque and near the outlet of Lomas Lake individual basaltic sheets at least 50 feet thick can be recognized by poorly developed columnar jointing. Farther south on the west slope of Mount Landalt near the base of the sequence, amygdules are present and are locally abundant. These features suggest that the basal and possibly other members of the basaltic sequence grade into shallow intrusive or possibly extrusive rocks.

The next exposures of the Franklin Creek volcanics to the south are on the peninsula at the east end of Cowichan Lake. Most of the basaltic rocks there are flows which overlie the chert and limestone of the Sicker group, but near Marble Bay, and as far as three-quarters of a mile west of Marble Bay, they intrude the chert and limestone. At other localities around the east end of Cowichan Lake, where the Franklin Creek basalt is exposed, as well as in the narrow belt extending northwest from the west end of Cowichan Lake, the rocks all appear to be extrusive.

East of the Cowichan Lake area, gabbros occur in sills, dykes, and irregular masses intruding the Sicker sediments. Clapp described them as the Sicker gabbro-diorite porphyrite (Clapp and Cooke, 1917, p. 169) and included them in the Sicker group because of their close association with the Sicker sediments. Masses of porphyrite in the Duncan area are continuous with intrusive diabase in the northeastern part of the Cowichan Lake area. The diabase has been mapped by the present writer as part of the Franklin Creek volcanics because of the marked lithological similarity and close spatial relationship between the intrusive and extrusive rocks, and because on Mount Landalt and El Capitan the intrusives appear to grade into shallow intrusives or flows. Flow rocks of the Franklin Creek volcanics overlie the Sicker group, and the intrusives are not known to cut rocks younger than this group, though obscure intrusive relations undoubtedly exist within the Franklin Creek volcanics. It has therefore been concluded that the Sicker gabbro-diorite porphyrite of the Duncan area forms part of the Vancouver rather than part of the Sicker group.

The thickness of the Franklin Creek volcanics is difficult to estimate because gently dipping sections are incomplete at the top, and complete sections are complicated by faulting or undetermined complex structures. Incomplete sections in the Mount Landalt-Mount Service region are 2,500 to 3,000 feet thick, and those on the ridge southwest of Rift Creek are as much as 3,500 feet thick. What appears to be a complete section is exposed on the peninsula at the east end of Cowichan Lake and on the hills west of Gordon Bay. The structure of the basalt in this area, however, is uncertain because part of the section is covered by the lake and by Upper Cretaceous sediments. The structure of the rocks on the hills west of Gordon Bay is discussed on page 24, and it is concluded that they form either a simple southwesterly dipping monocline or an overturned anticline. If the structure on the hills west of Gordon Bay and in the rest of the section is monoclinal, the Franklin Creek volcanics between the top of the limestone of the Sicker group on the peninsula and the base of the Sutton limestone are probably as much as 10,000 feet thick. If the structure on the hills west of Gordon Bay is anticlinal, the Franklin Creek volcanics are only 6,000 to 7,000 feet thick.

Sutton Limestone and Related Sediments.—The term "Sutton formation" was applied by Clapp "to include all of the intercalated limestones in the Vancouver volcanics of southern Vancouver island" (Clapp, 1912, p. 61). From fossils collected by Clapp at the type locality on the south shore of Cowichan Lake 3 miles northwest of Sutton Creek the age of the limestone was determined to be Lower Jurassic (Clapp and Shimer, 1911). The fossil forms, however, were new at that time, and subsequent work has shown them to be Upper Triassic (Martin, 1916; Shimer, 1926). Clapp, however, mapped all the limestone as part of the Vancouver group, not recognizing that some of the limestone was Palæozoic and hence should not be included in the Vancouver group. In this report, therefore, the Sutton limestone has been defined more precisely as the limestone of the Vancouver group that conformably overlies the Franklin Creek volcanics or their equivalents.

The Sutton limestone and related sediments outcrop on the south side of Cowichan Lake and northwest of the west end of the lake. The sediments dip southwestward, and only the lower part of the sequence was studied in mapping the Cowichan Lake area.

The Sutton limestone is fine grained, grey, grey-brown, or grey-blue, and commonly argillaceous.* Except where fossiliferous, it is massive or vaguely banded, but contains small irregular masses of chert and is cut by veinlets of white calcite. Fossils including colonial corals, bryozoans, pelecypods, and gastropods are locally abundant. In the Cowichan Lake area the limestone has a maximum thickness of about 500 feet and grades along strike into fine-grained green or brick-red clastic sediments. Both the limestone and the sediments into which it grades are underlain by Franklin Creek basalt and overlain by clastic sediments.

The sediments overlying the Sutton limestone include brick-red, green, dark-grey, and brown argillaceous sediments. They are overlain by fine-grained breccias and feldspathic sediments partly of volcanic origin. Basaltic flows were seen in the rocks above the Sutton limestone south of Cowichan Lake, but were not seen elsewhere.

At the type locality on the south side of Cowichan Lake, due south of Youbou, limestone is exposed along the beach for a distance of about 600 feet. The shore slopes gently northward, the beds strike slightly east of north, and erosion-resistant beds form several promontories a few tens of feet wide and a few hundred feet long. The beds have a relatively uniform attitude striking north 15 to 35 degrees east and dipping 40 to 60 degrees westward. The following table shows the sequence exposed on the beach.

SEQUENCE OF ROCKS EXPOSED AT THE TYPE LOCALITY OF THE SUTTON LIMESTONE

	Approximate Thickness (Feet)	Lithology
		Pyroclastics and other sediments.
Sutton limestone.	50	Green tuffaceous sediments, minor white limestone with interbedded thin basaltic flows.
	75	No exposures.
	2	Coral limestone containing mainly the species *Thecosmilia fenestrata.*
	10–20	Grey limestone locally shell-bearing, base marked by bed of fossil tree-trunks.
	150–160	Grey to white limestone.
	2–4	Shell-bearing limestone.
	50	Fine-grained grey limestone locally containing broken shell fragments.
	5–6	Coral limestone rich in colonial forms, mainly the genus *Isastrea.*
	80–90	Grey limestone containing a few bands rich in carbonaceous matter and locally concretionary.
	1	Shell-bearing limestone.
	35–40	Grey fine-grained limestone with thin bands of carbonaceous matter.
	20–50	Green to black amygdaloidal volcanics (top of Franklin Creek volcanics).

* Several specimens analysed spectrochemically contained less than 1 per cent magnesium.

Several fossil collections were made from rocks exposed on the lake-shore and submitted to the Geological Survey of Canada for identification, but fossil tree trunks were the only new forms discovered. These appear as irregular and elliptical cylinders of black and white coarsely crystalline calcite and carbonaceous material in the normal dense grey limestone. The largest piece found was 6 inches by 1 foot in cross-section and about 3 feet long. Smaller pieces are abundant, forming the greater part of a bed 2 to 3 feet thick. The specimens appear broken and lie with long axes parallel to the bedding, apparently originating as small logs washed into place in shallow water. Of the specimens sent to the Geological Survey of Canada, F. H. McLearn reports as follows: "In parts of the specimens wood and bark are replaced by lime, with retention of cellular, woody structure; this is true petrifaction presumably of coniferous wood by replacement. In addition there is a filling with crystals of calcite. The black nodules, irregular black masses, and some black bands consist of carbon. They appear to have originated by the action of some kind of 'coal-making' process or 'coalification' and to be of a substance like 'opaque' coal which occurs in durain, a constituent of coal."

The limestone at the type locality continues southward, but outcrops are scarce and the well-banded fossiliferous character does not continue.* About half a mile south of the lake at an elevation of 1,200 feet the limestone either grades into non-calcareous sediments or is covered by Upper Cretaceous sandstone. Some 1,500 feet farther south along the strike of the beds, limestone similar to that near the lake forms a band extending southeastward and eastward about a mile to a point where it either pinches out or passes beneath the Upper Cretaceous sediments in the valley to the east. The contact between the limestone and the Benson conglomerate is not exposed at this point. The most easterly outcrops of limestone contain many irregular pods of greenstone as well as small masses of skarn. The true relations are obscure, and it is not known whether the limestone continues east beneath the Upper Cretaceous sediments or pinches out west of them.

Amygdaloidal basalt, with minor interbedded pyroclastics and lenses of limestone, outcrops on the north and northeast slopes of the hill† about a mile west of Gordon Bay, and underlies the Sutton limestone. The stratigraphic sequence and thickness of these rocks between the base of the Sutton limestone and the most northeasterly band of limestone in the Franklin Creek volcanics is uncertain because the massive nature of the rocks makes the determination of the structure difficult. The Sutton limestone at the type locality is stratigraphically right-side up, as indicated by indigenous corals in the limestone that branch westward, by pelecypod shells in a bed near the base of the limestone that are convex westward, and by poorly graded bedding in green sediments at the top of the formation. The beds dip 40 to 50 degrees westward, and farther south they dip more steeply southward. The isolated mass of limestone on the southwest slope of Blue Grouse Hill (*see* Fig. 2) appears to dip less steeply than the slope of the hill forming a coating of limestone almost parallel to the hillside. This field evidence indicates that the Sutton limestone in this area is either part of a southwesterly dipping regional monocline or forms the southwest limb of an anticline.

Lenses of limestone a few feet thick and a few tens of feet long occur in the volcanics for several hundred feet below the Sutton limestone. They are well exposed along the shore of Cowichan Lake and are poorly exposed on Blue Grouse Hill. Amygdaloidal and massive volcanics outcrop northeast of the Sutton limestone, almost certainly underlying it as well as the small limestone lenses. The band of limestone that emerges from beneath the Cretaceous sediments about a mile east and half a mile south of the Sutton type locality dips steeply southwestward. This limestone is very fine grained, generally massive, contains no fossils, and resembles limestone of the Sutton formation. No field evidence could be found for the structural position of this limestone, but judging from the steep dip and the occurrence of overturned structures north of the lake, it may be

* During 1954, limestone containing fossils and resembling the Sutton limestone was exposed in trenches on the Blue Grouse property near the top of the hill east of the main band of limestone.

† Known locally as Blue Grouse Hill.

on the northeast limb of an overturned anticline. The limestone is not Sutton limestone repeated by folding, however, as rocks to the northeast are amygdaloidal and not the sediments that normally overlie the Sutton limestone. If the rocks on Blue Grouse Hill form an anticline, an estimated 1,000 feet of volcanics with limestone and sedimentary lenses near the top occur between the base of the Sutton formation and the oldest band of limestone in the Franklin Creek basalt. If the structure is a simple monocline, this thickness of volcanics and sediments may be 2,000 to 3,000 feet. At other localities there appears to be no limestone in the Franklin Creek volcanics below the Sutton limestone.

The Sutton limestone outcrops again in Redbed Creek, a south- and westward-flowing tributary of Nitinat River. The limestone is exposed in the bed of the creek for a distance of about half a mile downstream from the point where it begins to flow westward. The creek follows the bedding of the formation cutting across short sections at widely separated points. Outcrops are scarce on each side of the creek, and it is difficult to obtain a good section.

The limestone occurs as lenses in the brick-red tuffaceous sediments that overlie the Franklin Creek basalt. It is grey to black very fine grained limestone containing fossils essentially the same as those at the type locality. Fossils identified by F. H. McLearn, of the Geological Survey of Canada, include "*Monotis* sp.," "*Isastrea* sp.," and "bones of a marine reptile." *Isastrea* is abundant in a horizon 50 to 100 feet below that containing *Monotis*. The "Isastrea beds," containing many colonial corals, and the "Monotis beds," composed of a mass of pelecypods and other shell fragments, so strongly resemble those at the type locality that there is no doubt that they belong to the same formation. Similar limestone is found in the next tributary of Nitinat River northwest of Redbed Creek. It is poorly exposed for about 150 feet along the bank of the tributary, and overlies red clastic sediments, which in turn overlie Franklin Creek basalt. To the northwest, the base of the sequence of red sediments can be seen in the southeastward-flowing tributary of Nitinat River about half a mile south of the confluence of Rift Creek and Nitinat River. Several hundred feet of sediments, dipping southwestward parallel to the contact with the volcanics, overlie Franklin Creek basalt in this section, but they contain no limestone.

Structure of the Pre-granitic Rocks

Rocks of the Sicker and Vancouver groups appear to form a conformable sequence. Where contacts between adjacent formations and groups are exposed, the beds either above or below are parallel to the contact. This observation at individual outcrops is substantiated in mapping; the trace of the contacts on surface closely follows the shape expected from the attitude of the bedding. This parallelism of beds with the contact does not constitute proof of conformity at places where the underlying rocks are massive. However, the general similarity of the structures, the fairly uniform degree of metamorphism, and the interbedding of formations at some contacts and lack of erosional features at others indicate that there is no marked orogenic or erosional break within the sequence. The lens-like nature of some of the sediments and the few occurrences of coarse conglomerate suggest the presence of local disconformities, though none was recognized in the field.

At least two periods of deformation can be distinguished, each probably extending over a considerable length of time. The rocks were folded prior to the intrusion of the Saanich granodiorite, as indicated by the fact that relatively undeformed granodiorite cuts across folds of the older rocks. Upper Cretaceous sediments unconformably overlie the volcanic sequence and the Saanich granodiorite. The unconformity at the base of the Cretaceous sediments at places dips as steeply as 50 degrees and the beds lie essentially parallel to the surface of unconformity. In addition, the Upper Cretaceous sediments are folded and cut by faults of relatively large displacement. Hence the volcanic sequence, as well as having been deformed before the intrusion of the granodiorite, was broken by faults and moderately folded at the same time as the Upper Cretaceous sediments.

Details of the structure of the volcanic sequence are frequently difficult to determine because of the lack of horizon markers, the lens-like nature of many of the bedded rocks, and the massive character of some of the formations. Thus, in the western half of the map-area the structure has not been worked out with assurance, but in the eastern half, where bedded sediments in the Sicker group form a large part of the rocks exposed, the general structure has been fairly accurately defined.

The rocks are folded along northwesterly trending axes. In most of the area the axial planes dip southwestward and the folds are either overturned or asymmetric. Toward the northeastern part of the area, in particular northeast of Chemainus River, the dip is mainly north and northeast, and the folds appear to be asymmetric with axial planes dipping northeastward.

The regional plunge of the structures averages a few degrees to the north and northwest throughout the area. Locally, however, the folds plunge steeply, and small folds across the regional trend of the structures are common. Near the head of Shaw Creek, for example, sediments of the Sicker group form a northerly trending asymmetric syncline plunging a few degrees northward. Locally in that area the main folds plunge as much as 45 degrees northward. Similarly, at the head of Meade Creek, where regionally the folds trend west and northwest, some beds strike northward and dip as steeply as 60 degrees westward. Overturned folds are exposed in the area around the east end of Cowichan Lake and along the north side of the lake as far west as Shaw Creek. The approximate positions of the axes of these folds have been sketched on the map (*see* Fig. 2). The position of some is readily determined, but others have been inferred from somewhat inadequate data.

A well-defined continuous syncline of cherty tuffs of the Sicker group extends from east of Meade Creek to Sherk Lake. It is overturned with axial plane dipping 50 to 60 degrees southwest. The northern limb throughout its length is broken by what appears to be a fault later than the Upper Cretaceous. In the Widow Creek valley the axis of the fold swings northward and the plunge changes abruptly. Through most of the length of the fold the plunge is very gently westward, but west of Mount Holmes it steepens, in Widow Creek it flattens again, and near Sherk Lake it reverses to southeastward. The beds are highly contorted in all of the Widow Creek area, except on the northern limb of the fold where they dip gently southwestward. On the hill west of Widow Creek the overturning of the western limb is accentuated by small faults that cut across the structure. An overturned syncline similar to that exposed in the Widow Creek area occurs west of the head of Cottonwood Creek.

No pre-intrusive faults have been recognized, except the small tear faults on the overturned limb of the fold west of Widow Creek, referred to above. The actual fault zones are not exposed, but the faults are indicated by offsetting of the beds.

Regional Significance of the Pre-granitic Stratigraphy

One of the chief problems of the geology of southern Vancouver Island is the age and stratigraphic correlation of the pre-granitic rocks. In early work by Clapp and others these rocks were subdivided, and the Sicker series and Sutton limestone were named. In addition, the age of one lens of limestone, that at the type locality of the Sutton limestone on the south shore of Cowichan Lake, was determined. The age of the other limestones, their relation to Vancouver and Sicker groups, and the relation of the Sicker to the Vancouver group were left uncertain. Subsequent work farther north on Vancouver Island by Gunning, Sargent, Stevenson, and others established stratigraphic sequences that could not be correlated readily with Clapp's sequence in the southernmost part of Vancouver Island. The present study in the Cowichan Lake area has provided data of significance in solving some of these problems.

Tracing of the Sicker group westward from the Duncan area has shown that it is overlain by basaltic rocks that form the lowest part of the Vancouver group (*see* p. 19). Hence the Sicker group underlies the Vancouver group. Whether the contact is one of conformity or disconformity is uncertain. The upper members of the Sicker group appear at places to be abnormally thin, and the same rock type in the Sicker group does not everywhere occur beneath the massive volcanics of the Vancouver group. This apparent evidence for disconformity may be a result of the intrusive sill-like nature of some of the Franklin Creek volcanics. Hence proof of conformity or disconformity has not been established.

The age of the Sicker group hinges on relatively poor fossil evidence (*see* p. 19) and on the correlation of the crinoidal limestone on the peninsula at the east end of Cowichan Lake with that on the western slope of Mount Landalt (*see* p. 19). In the opinion of the writer this correlation is correct, and consequently rocks of the Sicker group are thought to be Lower Permian and older. More geological work is necessary, however, to prove this definitely and to establish a stratigraphic subdivision of the Sicker group. The crinoidal limestones south of Lake Cowichan extend eastward into the Duncan area. These limestones and associated sediments, which form a belt a few miles wide along the south side of Cowichan Valley extending as far east as Cobble Hill (Clapp and Cooke, 1917, Map 42A), probably belong to the Sicker group, as implied by Mathews (1946, Fig. 20). Permian limestones and sediments associated with them that have been recognized in the China Creek area and near Horne Lake can probably be correlated with the Sicker group. Correlations with more distant areas on Vancouver Island are more speculative, but possibly Permian limestones and associated sediments in the Buttle Lake and Bedwell River areas may also be regarded as part of the Sicker group.

The Sutton limestone at the type locality overlies a thick sequence of massive basalts that form the lowest part of the Vancouver group. These basalts in the Cowichan Lake area belong to the Franklin Creek volcanics. Not all lenses of limestone described by Clapp as the Sutton limestone are at or near the horizon represented at the type locality. Many probably belong to the Sicker group, others may be equivalent to that at the type locality, and still others may belong to other horizons. The writer proposes that the term " Sutton limestone " include only limestone of the Vancouver group that conformably overlies the Franklin Creek volcanics or their equivalents. It has been shown that the Sicker gabbro-diorite porphyrite of Clapp (Clapp and Cooke, 1917, p. 169) is probably part of the Vancouver group and an intrusive phase of the Franklin Creek volcanics.

SAANICH GRANODIORITE

Granitic rocks ranging in composition from quartz diorite to siliceous granite intrude the Vancouver and Sicker groups. Similar rocks to the east, in the Duncan area, and in part continuous with those in the Cowichan Lake area, have been termed Saanich granodiorite from their occurrence on Saanich peninsula (Clapp, 1912, p. 101; 1913, p. 71). The name " Saanich granodiorite " or merely " granodiorite "* is used here for all granitic rocks in the Cowichan Lake area. The granodiorite intrudes Upper Triassic rocks southeast of Honeymoon Bay and at the head of the southwest fork of Nitinat River and intrudes older formations north of Cowichan Lake. Along Chemainus River, near the

* Where granodiorite and other rock names are used to denote rocks of specific compositions, the classification of Grout (1932) has been used. Granite, quartz monzonite, granodiorite, and quartz diorite are defined as light-coloured, fine-, medium-, or coarse-grained rocks containing quartz, feldspar, and minor amounts of dark minerals. They are subdivided on the proportion of the alkalic feldspar (potash feldspar and albite) and medium plagioclase (oligoclase and andesine), and on the dark mineral content as follows:—

Granite—alkalic feldspar more than two-thirds of the total feldspar.

Quartz monzonite—alkalic feldspar one-third to two-thirds of the total feldspar.

Granodiorite—medium plagioclase more than two-thirds of the total feldspar, dark minerals less than 10 per cent.

Quartz diorite—medium plagioclase more than two-thirds of the total feldspar, dark minerals more than 10 per cent.

Aplogranite is a type of light-coloured granite containing more potash feldspar than albite and a very small proportion of dark minerals.

head of the west fork of Meade Creek, and southeast of Honeymoon Bay, the granodiorite is unconformably overlain by Upper Cretaceous sediments of the Nanaimo group. These relationships demonstrate that it was emplaced before the Upper Cretaceous and after the Triassic. Saanich granodiorite and rocks of similar age and composition on Vancouver Island in general are commonly correlated with the Coast instrusions of the mainland of British Columbia.

Summary

Plutons of granodiorite in the Cowichan Lake area are steeply dipping, irregular dyke-like bodies, the long axes of which are approximately parallel to the axes of folds in the older rocks. In cross-section the plutonic masses cut across the complex structures of the pre-granitic rocks. In composition the Saanich granodiorite ranges from quartz diorite to aplogranite. Quartz diorite is more common in the eastern part of the area than in the western near Mount Buttle, whereas aplogranite occurs only as a roof facies in protrusions into the volcanic rocks near the top of Mount Buttle. The granodiorite is massive and everywhere contains a low proportion of small, rounded, mafic inclusions.

The pre-granitic basic volcanics have undergone a low grade of regional metamorphism. In the lowest grade of metamorphism, actinolitic hornblende and minor amounts of clinozoisite have developed, and in a somewhat higher grade ragged hornblende, biotite, epidote, and probably a more sodic plagioclase have formed. In contact metamorphism the basaltic rocks have been recrystallized and changed in composition so that they exhibit granoblastic textures and contain minerals characteristic of the granodiorite. The regionally metamorphosed rocks appear to be spatially related to granitic masses. They may be regarded as a " basic front," whereas the zone of contact metamorphism is one of granitization.

The Saanich granodiorite is probably of magmatic origin. It appears to have been emplaced by passive processes involving stoping. Small mafic inclusions and larger fragments of wallrock in the granodiorite are regarded as remnants of stoped blocks. Crystallization of the granodiorite and its facies probably involved basification of the original magma by contamination, migration of a late felsic differentiate to form the aplogranitic facies, and development of relatively large crystals of potash feldspar in the granodiorite, mafic inclusions, and wallrock, largely by replacement of plagioclase.

Size, Shape, and Relation of the Granodiorite to Structure

Plutons of granodiorite in the Cowichan Lake area are elongate and trend northwestward. The largest entirely within the area is about 8½ miles long, less than 1½ miles wide, and extends from the ridge about a mile north of Youbou to the hills around Delphi Lake. A similar pluton about 10 miles long and less than 1½ miles wide extends eastward from Mount Good into the Duncan area, and about a dozen smaller ones are exposed in the northeastern part of the Cowichan Lake area.

Sides of the plutons in general dip steeply. Steep dips were observed at a few places, and elsewhere may be inferred from contacts that are relatively straight regardless of topography (*see* Fig. 2).

On Mount Buttle a cross-section of the upper part of one granodiorite pluton is exposed, and approximate form lines on the surface of the granodiorite in this area are shown in Figure 3. The form lines have been inferred from the observed attitude of the contact on Mount Buttle, from the shape of the trace of the contact on surface, and from the assumption that the granite on the ridge north of Delphi Lake was not far below the volcanic roof rocks before being uncovered by erosion (*see* p. 32). On Mount Buttle, volcanics overlie the granodiorite along the ridge between Peaks Two and Three. The upper contact of the granodiorite is essentially horizontal on the north side of the ridge, and forms a shallow trough on the south side. West of Peak Two, irregular dyke-like protrusions of aplogranite cut through the volcanic capping. West of Peak Three a similar northerly trending apophysis extends upward into the volcanics and is exposed on both sides of the ridge. To the east, the eastern side of the pluton strikes north and dips eastward more steeply than the east slope of Peak Three. To the west, the western side appears to be vertical or to dip steeply westward.

From these observations, in longitudinal section the crest of this body of granodiorite appears to be relatively gently curved, and in cross-section the top is irregular and the sides dip steeply outward. It has therefore been concluded that in the rest of the Cowichan Lake area elongate bodies forming a fairly continuous belt " along strike " are probably continuous in depth. For example, the elongate pluton extending southeast from Mount Buttle, the two small ones north and northeast of Youbou, and the one extending east from Mount Good are probably continuous beneath the volcanics and Upper Cretaceous sediments. Continuity in depth perpendicular to the long axes of the plutons, on the other hand, is less certain.

Regional geologic mapping on southern Vancouver Island is not complete enough to show the true relation of the dyke-like plutons to larger masses of Saanich granodiorite. In the opinion of the writer, bodies of granodiorite in the Cowichan Lake area are protusions that extend either laterally or upward from larger masses. A mile and a half northeast of the village of Lake Cowichan, one of the dyke-like plutons widens abruptly and continues southeastward with some interruptions as far as Saanich Peninsula (*see* Fig. 1), where it is more than 8 miles wide (Clapp, 1913, Map 72A). Relatively large areas 4 or 5 miles north and northwest of Mount Whymper are reported (Clapp, 1912, Map 17A) to be underlain by granitic rocks, and the masses of granodiorite along the north side of the map-area (*see* Fig. 2) may join a larger body to the north.

The large dyke-like plutons near Cowichan Lake have small dykes associated with them. A few of these extending upward and outward from the granodiorite on Mount Buttle are shown in Figure 3. Granitic dykes penetrate volcanics to distances of several tens of feet from granodiorite contacts and commonly dip steeply and strike about parallel to the long axes of the main body of granodiorite.

A few of these dykes near the granodiorite contact exposed in McKay Creek about 2 miles north of Cowichan Lake are sketched in Figure 6. They are massive granodiorite similar to that of the main body to the north. The longest are parallel to the regional trend of the granodiorite contact. The dykes commonly branch, and ends of smaller branches are wedge-shaped. Some of the narrowest dykes have matching walls, but wider ones are remarkably irregular and one wall in no way reflects the irregularities of the other. They contain well-defined angular fragments of wallrock, some of which look as if they could be fitted back into near-by irregularities in the walls. In Plate XII, for example, the bottom of the fragment at "A" appears to match the wall of the dyke just below it. None of the fragments shows banding that would indicate whether or not they have been rotated. At places, slivers of wallrock protrude into the dyke in such a way that the long axes of the slivers make acute angles with the dyke wall (e.g., upper dyke, Plate XII). The slivers resemble fragments incompletely detached from the walls, and the removal of such fragments may account for the lack of matching walls in many of the dykes. A key bed in the surrounding sediments is exposed on each side of one dyke, but whether or not it has been displaced by dilation is not certain as the dyke is irregular and almost perpendicular to the bed. Though the evidence is not definitely conclusive, it favours the hypothesis that the dykes at this locality are intrusive rather than replacive.

In plan, the axes of folds in the sedimentary and volcanic rocks and the long axes of the bodies of Saanich granodiorite are essentially parallel. In cross-section, however, the granodiorite cuts across the complex structures of the volcanics and sediments. These crosscutting relations, which are obvious on the map (*see* Fig. 2), can also be seen in the field where contacts between sediments and granodiorite are exposed. The plutons therefore appear to have been emplaced after the main period of deformation of the older volcanic and sedimentary rocks. The massive character of the granodiorite and the attitude of the overlying Upper Cretaceous sediments indicate that the plutons have been no more than slightly deformed since emplacement. The granodiorite is massive and displays no linear or planar structures. Poorly developed joints in the granodiorite have no obvious pattern. Commonly one set of joints dips gently and is essentially parallel to the present surface. Other sets dip steeply. The attitudes of 144 steeply dipping joints in the granitic rocks outlined on Figure 3 have been plotted on a stereographic projection. Many of the joints have an irregular attitude, and in collecting the data from which the diagram has been prepared, only the attitudes of regular joint planes were measured, and these were recorded to the nearest 5 degrees. The joints do not show any systematic variation in attitude from place to place, but combined they fall into what are probably two sets about at right angles to each other. The sets are nearly vertical; one strikes about north 35 degrees west and the other north 45 degrees east. The two individual maxima in the southeast quadrant of Figure 3 probably do not represent two distinct joint sets since the degree of accuracy of the data is low and the joints in general are not well defined. No slickensides were seen on any of the joint surfaces. The granodiorite has been epidotized adjacent to a few joints of both sets. Quartz-sulphide veins that cut the granitic rocks northwest of Peak Two are approximately parallel to the northwesterly trending joints. The quartz veins are thought to be genetically related to the granodiorite (*see* p. 32), and if so the northwesterly trending joints developed soon after the crystallization of the granodiorite.

Bodies of Saanich granodiorite have been more or less tilted and faulted in the deformation that affected the Upper Cretaceous sediments of the Nanaimo group (*see* p. 53). The unconformity at the base of the Nanaimo group dips as steeply as 50 degrees. Part of this dip is caused by the relief of the old erosional surface, but the larger part results from tilting during faulting. Northwesterly trending joints in the Saanich granodiorite near Mount Buttle probably developed early (*see* p. 48). They are parallel to and locally have been followed by the northwesterly trending faults that displace the Upper Cretaceous sediments.

Characteristics of the Granodiorite

The Saanich granodiorite as seen in the Cowichan Lake area for the most part is uniform in composition and texture. Clean outcrops are light grey, fresh surfaces are darker grey than weathered surfaces, and altered rocks are greenish-grey. The granodiorite is medium grained, and crystals of quartz, plagioclase, potash feldspar, hornblende, and biotite can be distinguished in hand specimens. Crystals of potash feldspar as much as 1 centimetre across commonly enclose smaller crystals particularly of plagioclase, and this poikilitic texture can at places be distinguished in hand specimens.

Only the more marked variations in the mineralogy of the granitic rocks are noticeable in the field. The small bodies between Widow Creek and Mount Good and the one on Mount Franklin, as well as narrow sections of the larger masses, contain a higher proportion of dark minerals than the normal granodiorite. Although large crystals of potash feldspar are visible under the microscope, they are frequently difficult to see in hand specimens. At many places, however, a low proportion of potash feldspar can be inferred from a scarcity of relatively large feldspar cleavage faces. Granite and aplogranite, recognized only in the vicinity of Mount Buttle, are distinguished readily from the granodiorite because they are even grained, and either lack dark minerals or contain only biotite.

Under the microscope the granodiorite is seen to be a medium-grained rock consisting of quartz, potash feldspar, hornblende, and biotite, with minor amounts of magnetite, apatite, zircon, and sphene (*see* Plate XIII). In general the minerals are fresh, but sericite, chlorite, and epidote occur as products of alteration in all thin sections studied.

Hornblende forms euhedral to subhedral, green to yellow-green, pleochroic crystals commonly altered to epidote or chlorite. Biotite, frequently associated with hornblende, is in subhedral crystals with brown to straw-yellow pleochroism. Lenses of prehnite between biotite cleavage flakes are common. Biotite is widely altered to chlorite, and chlorite pseudomorphous after biotite contains prehnite and grains of leucoxene along relict cleavage planes.

Plagioclase feldspar occurs as subhedral and anhedral zoned crystals. Centres of crystals are calcic andesine* or sodic labradorite and edges are oligoclase. In almost every crystal the anorthite content of the zones decreases gradually and regularly from the centre toward the edges. Very few show a reversal of this type of zoning, and reversals involve only one or two zones somewhere between the centre and the outside of the crystal and not the entire crystal. In addition to the ubiquitous albite twins, carlsbad and pericline twins are fairly common. Edges of plagioclase crystals adjacent to or enclosed in potash feldspar are scalloped, irregular, and locally contain fine myrmekite. Most plagioclase is partly altered to sericite and, where alteration is more intense, to fine crystals of clinozoisite. Centres of crystals are generally more highly altered than edges.

Potash feldspar occurs as relatively large anhedral crystals enclosing plagioclase and less commonly hornblende and biotite. Typical crystals are 6 to 7 millimetres across while those of the enclosed minerals are less than 2 millimetres. Where not abundant, potash feldspar is interstitial and crystals are relatively small. Blebs and lamellæ, probably of plagioclase too fine for identification, are present in virtually all the potash feldspar. Carlsbad twins are fairly common, but crystals are not otherwise twinned, though some orientations show wavy extinction. Determinations of $X \wedge 010$ by direct measurement on the universal stage indicate that most of the potash feldspar is orthoclase-microperthite, but some is probably microcline-microperthite since values of $X \wedge 010$ ranging from 0 to 14 degrees have been measured.

Quartz is present as anhedral crystals with wavy extinction and contains many minute liquid inclusions.

Magnetite is the most abundant accessory, but apatite is present in all thin sections studied, and sphene and zircon are common.

Characteristics of the Aplogranitic Facies

At several places in the vicinity of Mount Buttle the granodiorite grades into granite, which in turn grades into aplogranite. The granite and the more abundant aplogranite are referred to as the aplogranitic facies. The distribution of the aplogranitic facies in the vicinity of Mount Buttle was outlined in the field, though the range in composition within the facies could only be inferred at that time. It occurs in three irregular masses between granodiorite and volcanics on Mount Buttle, in an isolated mass in granodiorite on the ridge north of Delphi Lake, and in a small body surrounded by volcanics northwest of Mount Buttle (*see* Fig. 3).

The two masses of aplogranite exposed on each side of the ridge west of Peak Three are almost certainly continuous beneath the volcanics, forming an elongate apophysis above the granodiorite. The contact between granodiorite and granite is gradational, distinguished by a change in dark minerals from hornblende and biotite in the granodiorite to biotite only in the granite. Biotite granite above the granodiorite is 10 to 20 feet thick. It grades upward into the aplogranite which makes up most of the aplogranitic facies. The change from granodiorite to aplogranite takes place over a distance of a few tens of feet, and the rock maintains its massive character across the contact zone. As closely as could be determined, the trace of the contact zone is horizontal and at about the same elevation on each side of the ridge. Consequently, the contact zone is probably relatively flat and almost horizontal.

The dyke-like masses of aplogranite between Peaks One and Two form apophyses above the granodiorite. Southeast of the pass between Peaks One and Two the contact zone is horizontal but 300 to 400 feet higher than that southwest of Peak Three.

* Composition of plagioclase has been determined by Michel Levy's method and by measurement of extinction angles on oriented sections where these could be recognized. Plagioclase of selected thin sections (*see* tables on pages 34 and 40) was determined on the universal stage using the Rittmann zone method (Emmons, 1943, p. 121).

North of Peak Two the contact zone is horizontal but about 300 feet lower than on the southeast slope of Peak Two. It thus appears to dip gently northward beneath Peak Two, and northwest of Peak Two it probably dips northwestward. The form of the band of aplogranite extending north along the granodiorite contact west of Delphi Lake is uncertain as the aplogranite is poorly exposed and none of the contacts were seen. The presence of aplogranite in the depression about 3,500 feet northwest of Peak Two suggests that the volcanic contact dips gently westward and that the granite may form a relatively thin tabular body dipping and tapering northwestward.

Quartz-sulphide veins cut this body of aplogranite as well as the granodiorite west of Delphi Lake between elevations of about 2,800 and 3,800 feet (*see* Fig. 3). Most of the veins are within 700 feet of the edge of the plutonic mass. They range from a fraction of an inch to about 4½ feet wide, strike between north and northwest, and dip steeply eastward. They contain white, commonly vuggy quartz, flakes and rosettes of molybdenite, and clusters of pyrite. The quartz veins are thought to be genetically related to the granodiorite because the aplogranite contains molybdenite as a minor accessory, and because in all the Cowichan Lake area quartz-molybdenite veins are found only in or very close to granodiorite plutons.

Aplogranite on the ridge north of Delphi Lake may overlie the granodiorite in the same way as the aplogranite on Mount Buttle. The regular shape of the mass north of Delphi Lake and its occurrence only on the crest of the ridge support this conclusion, but poor outcrops in the vicinity make it uncertain. A diagrammatic projection of the volcanic roof of the granodiorite northward from Mount Buttle and westward from the low hill to the east suggests that the aplogranite on the ridge north of Delphi Lake may not have been far below the volcanics before being exposed by erosion. From these few observations it has been concluded that the aplogranite north of Delphi Lake forms a gently dipping tabular body overlying the granodiorite.

Thus the aplogranitic facies near the top of Mount Buttle is a roof facies in apophyses at the top or uppermost end of a large dyke-like mass of granodiorite. North of Delphi Lake the aplogranite probably occupies a similar position. West of Delphi Lake the aplogranitic facies appears to follow the margin of the granodiorite but, as shown above, it may form a gently dipping tabular mass below the volcanics and may also be a roof facies. Aplogranite has not been seen elsewhere in the Cowichan Lake area, though very small masses of leucogranite* occur at the ends of narrow dykes in some contact zones (*see* p. 43).

In the field the aplogranite is a white, commonly rust-stained siliceous rock. Seen in thin section it is equigranular and made up of anhedral crystals of quartz, orthoclase-microperthite, and sodic plagioclase averaging 0.3 millimetre across (*see* Plate XIII). Biotite is present in the aplogranite as sparse flakes, some of which appear bent. Magnetite and apatite are common accessories, pyrite is a minor accessory, and molybdenite is rare.

Plagioclase ranges in composition from sodic albite to calcic oligoclase. The crystals are very slightly zoned, but optic studies show that this range in composition may exist in one thin section. Chemical analyses (*see* table, p. 37) indicate that the average anorthite content of the plagioclase decreases upward away from the granodiorite. A few crystals have a narrow, well-defined rim of sodic albite. Edges of plagioclase crystals adjacent to orthoclase-microperthite are "corroded," and locally myrmekitic.

Orthoclase-microperthite† contains lamellæ of albite, many of which are regular and lie parallel to the (100) crystallographic direction. Regular lamellæ grade into irregular patches or veinlets which extend to the edges of the host crystal and form small masses of clear albite between it and adjacent crystals. Albite related to the potash feldspar can be distinguished from other crystals of sodic plagioclase as the latter contain sericite, while the former do not. Locally, albite of the orthoclase-microperthite fills

* A light-coloured granite containing more albite than potash feldspar.

† In all the aplogranite the potash feldspar has $X \wedge 010 = 0$ and $2V_X = 55\text{-}65$ degrees.

in small fractures cutting sericitized crystals of sodic plagioclase. The most siliceous aplogranite, near the roof of the body, contains a micrographic or granophyric intergrowth of quartz and orthoclase-microperthite.

As can be seen from the above descriptions, the aplogranitic facies differs markedly from the normal granodiorite, but because the granodiorite grades upward through granite into aplogranite, the more siliceous rocks are regarded as facies genetically related to the granodiorite. Differences in microscopic features are summarized in the following table.

MICROSCOPIC FEATURES OF THE GRANODIORITE AND APLOGRANITIC FACIES

	Granodiorite and Quartz Diorite	Aplogranitic Facies
Texture	*Hypidiomorphic with poikilitic potash feldspar*	*Allotriomorphic, equigranular, locally micrographic.*
Dark minerals	Hornblende and biotite (> 5%)	Biotite (< 5%).
Plagioclase	Zoned andesine-oligoclase	Unzoned albite-oligoclase.
Potash feldspar	Microcline- and orthoclase-microperthite with blebs and very fine lamellæ of albite (?)	Orthoclase-microperthite with blebs and somewhat coarser lamellæ of albite.

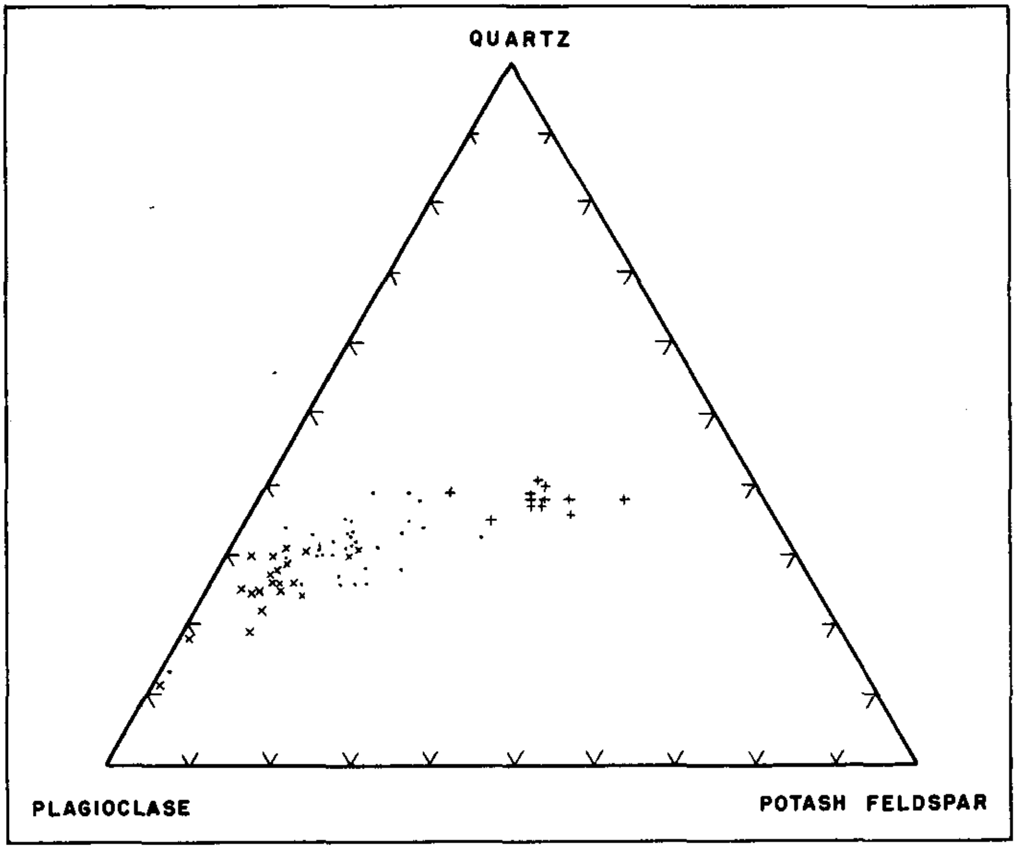

Figure 4. Triangular diagram showing mineralogical analyses of the Saanich granodiorite. Aplogranitic facies shown by +, granodiorite in the vicinity of Mount Buttle by single dots, other masses of Saanich granodiorite by x.

Mineralogical Composition

The mineralogical composition of the granodiorite as determined by thin-section analyses* is given on pages 34 and 35. Locations of samples analysed are shown on

* Thin sections cut from single hand specimens were analysed by means of a point counter. Analyses were made of good-sized thin sections without holes, and in each about 1,300 points were counted. Results are probably within a few per cent of the true composition of the thin section but vary in accuracy with the extent of alteration. Analyses of the most highly altered specimens that were thought to be of doubtful accuracy have not been included.

Figures 2 and 3. Most of the bodies of granodiorite have not been adequately sampled and some have not been sampled at all. Analyses shown, however, are thought to represent the normal composition of a considerable volume of rock close to points where hand specimens were collected. No analyses of abnormal rocks, such as the mafic inclusions, are included. All the rocks are either granodiorite or quartz diorite in the classification of Grout (1932), except those near the upper part of Mount Buttle and on the ridge north of Delphi Lake where the granodiorite grades upward through granite into aplogranite.

In Figure 4, modal analyses of the granodiorite and its facies (data from pages 34 and 35 in weight per cent) have been plotted on triangular co-ordinates of quartz, potash feldspar, and plagioclase. The analyses lie within a fairly well defined belt extending from quartz diorite on the left to aplogranite on the right. They fall into three somewhat overlapping groups—the aplogranitic facies, the granodiorite in the vicinity of Mount Buttle, and the granodiorite and quartz diorite of other masses in the Cowichan Lake area. The transition from granodiorite to aplogranite on Mount Buttle is relatively abrupt, and only a few samples from the transitional zone have been analysed. This accounts for the scarcity of analyses in the range between the aplogranite and the granodiorite. In general the granodiorite in the vicinity of Mount Buttle contains more potash feldspar and less plagioclase than Saanich granodiorite from the rest of the Cowichan Lake area. These differences are normally accompanied by a lower proportion of mafic minerals in the granodiorite near Mount Buttle than in the samples from other parts of the area. Too few analyses are available to be certain, but analyses of granodiorite from the area shown on Figure 3 in general show a slightly higher proportion of mafics near the edges than in the centre of the granitic body. Similarly, in other parts of the Cowichan Lake area smaller masses of Saanich granodiorite and narrow parts of large masses are more mafic than most of the large masses.

VOLUME PER CENT OF MINERALS IN SPECIMENS OF SAANICH GRANODIORITE

Specimen No.	Quartz	Potash Feldspar	Plagioclase	Biotite	Hornblende	Accessories[1]
85 (Map Reference 1, Fig. 2)	20.2	9.8	52.9	6.5	9.1	1.5
550 ,, ,, 2 ,,	27.4	8.3	53.8	4.3	5.3	0.9
549 ,, ,, 3 ,,	24.5	6.2	53.3	3.5	10.9	1.6
548 ,, ,, 4 ,,	22.4	7.2	57.8	5.0	7.2	0.4
78 ,, ,, 5 ,,	23.0	5.9	56.0	4.5	10.0	0.6
536 ,, ,, 6 ,,	24.0	4.8	51.3	7.3	12.1	0.5
537 ,, ,, 7 ,,	20.7	3.2	58.0	6.8	9.8	1.5
575 ,, ,, A ,,	20.2	4.5	57.5	5.8	11.1	0.9
539 ,, ,, 8 ,,	20.4	7.8	53.9	5.8	10.9	1.2
36 ,, ,, 10 ,,	7.7	0.9	62.5	8.7	18.3	1.9
43 ,, ,, 11 ,,	21.2	5.3	58.6	4.5	9.4	1.0
220 ,, ,, 12 ,,	24.6	6.9	57.2	7.4	3.5	0.4
556 ,, ,, 13 ,,	19.0	6.8	58.6	5.4	8.5	1.7
173 ,, ,, 14 ,,	25.8	13.4	48.0	4.9	7.1	0.8
25 ,, ,, 15 ,,	13.7	0.2	59.9	7.4	18.4	0.4
41 ,, ,, 16 ,,	17.8	8.2	57.8	3.4	12.3	0.5
59 ,, ,, 17 ,,	20.7	5.5	53.8	2.7	16.1	1.2
312 ,, ,, 18 ,,	26.0	3.4	57.7	6.8	5.6	0.5
313 ,, ,, 19 ,,	15.9	7.4	61.1	4.9	9.7	1.0
180 ,, ,, 20 ,,	22.2	9.0	53.0	4.0	10.8	1.0
91 ,, ,, 21 ,,	25.7	5.9	52.5	5.0	10.5	0.4
324 ,, ,, 22 ,,	25.8	14.3	45.5	8.3	5.9	0.2
Mount Buttle and Vicinity (See Fig. 3)						
108	29.4	8.6	52.0	3.0	6.1	0.9
114	8.6	0.6	58.0	4.7	26.7	1.4
119	35.8	12.3	43.0	6.5	1.8	0.6
270	31.4	4.4	55.1	3.0	5.0	1.1
271	37.2	34.8	27.8	0.2	.....	+
280	38.5	23.7	37.1	——	.....	0.7
281	37.0	44.5	18.2	0.2	....	0.1
282	27.0	13.2	44.2	5.4	9.5	0.7
285	39.2	35.1	25.0	0.7	.....	+

[1] Mainly magnetite.

Specimen No.	Quartz	Potash Feldspar	Plagioclase	Biotite	Hornblende	Accessories[1]
286	36.2	34.9	27.4	1.4	......	0.1
407	28.0	13.1	49.2	4.1	5.3	0.3
408	31.3	19.6	44.3	3.4	0.8	0.6
409	33.9	40.3	24.6	0.9	......	0.3
410	38.5	33.4	27.5	0.3	......	0.3
422	28.7	13.1	45.6	4.4	5.5	0.7
424	38.2	20.6	27.5	12.7	......	0.9
426	39.3	33.2	25.2	2.3	......	+
428	36.2	35.4	27.3	1.1	......	+
432	36.9	18.3	40.5	3.7	......	0.6
433	35.6	19.8	39.6	4.5	.	0.5
434	29.1	13.7	47.7	4.9	3.8	0.8
435	22.8	13.3	49.2	6.5	7.1	1.1
436	25.2	15.9	45.2	5.2	7.7	0.8
437	28.1	17.0	46.3	5.7	2.4	0.5
438	34.1	29.8	33.0	3.0	......	0.1
439	36.6	45.5	16.8	0.6	......	0.5
440	37.7	38.9	22.9	0.5	......	+
444	32.5	19.5	41.4	5.0	1.2	0.4
445	36.0	39.1	24.0	0.5	......	0.4
448	21.4	8.9	50.5	6.7	10.8	1.7
450	27.4	41.7	23.0	2.6	4.6	0.7
453	26.3	10.7	45.8	6.0	10.0	1.2
456	27.6	26.0	31.3	4.9	8.8	1.4
457	27.2	10.2	50.9	4.6	6.1	1.0
458	26.8	10.6	52.5	2.5	6.9	0.7
578	24.4	19.8	44.2	3.4	7.5	0.7
579	25.8	6.6	54.7	4.7	6.6	1.6
582	22.5	9.5	54.6	5.1	6.8	1.5
583	26.4	9.9	49.3	3.3	9.5	1.6
588	30.8	20.5	39.5	3.5	5.0	0.7
589	22.6	16.1	48.0	3.5	7.4	2.4
590	22.5	14.3	49.8	3.5	9.1	0.8
592	26.1	12.0	50.0	4.6	6.6	0.7
596	23.4	4.2	52.6	8.6	10.2	1.0
597	21.8	16.0	45.6	5.4	9.6	1.6
600	30.4	11.3	44.4	8.2	4.6	1.1
601	28.8	13.0	46.9	6.2	4.2	0.9
602	31.0	11.4	46.0	5.6	4.5	1.5

[1] Mainly magnetite.

Chemical Composition

Chemical analyses of eight specimens of Saanich granodiorite are given on page 37. Seven analyses are of rocks from the Mount Buttle area, and the location of these is shown in figure 3. One (A) is from the west side of Cottonwood Creek about 2½ miles from its mouth.

In Figure 5 the chemical analyses have been plotted on a Harker type of variation diagram, and, as might be expected from the serial differences in the mineralogical composition of the samples, the oxides fall on relatively smooth curves. The curves bring out the range of composition in the granodiorite and aplogranitic facies on Mount Buttle. Analyses B and C are characteristic of the granodiorite on the southeast slope of Mount Buttle, and rocks of this composition grade upward through rocks represented by analyses D and F to those of composition G near the top of the aplogranitic facies on the south slope of Mount Buttle 2,000 feet east of the top of Peak Two. The same variation is indicated by the sequence of B-E-H, analyses B, E, and H representing rock types successively higher on the south slope of Peak Two. The change in texture from hypidiomorphic, characteristic of the granodiorite, to the allotriomorphic texture of the aplogranitic facies takes place between rocks of compositions D and E. Wide albite lamellæ in potash feldspar and micrographic textures are found only in the most siliceous rocks (analyses F, G, and H).

One chemical analysis of Saanich granodiorite from Saanich Peninsula (*see* Fig. 1), two of Colquitz gneiss, and one of Wark* gneiss from Victoria (Clapp 1913, pp. 59,

* "Wark gabbro-diorite" and "Colquitz quartz-diorite" form a gneissic complex at the southeast end of Vancouver Island, described by Clapp (1913) as early batholithic intrusives of the same cycle of plutonic activity as that in which the Saanich granodiorite was emplaced.

64, and 67) have been plotted on Figure 5. Within the silica range represented by the Cowichan Lake samples, the published and new analyses fall fairly well on the same curves. With the exception of Al_2O_3, the curves are well defined, and the fact that the analysis of Wark gneiss falls on the projection of the curves to lower silica percentages may be more than coincidence. If so, the analyses support the conclusion of Clapp

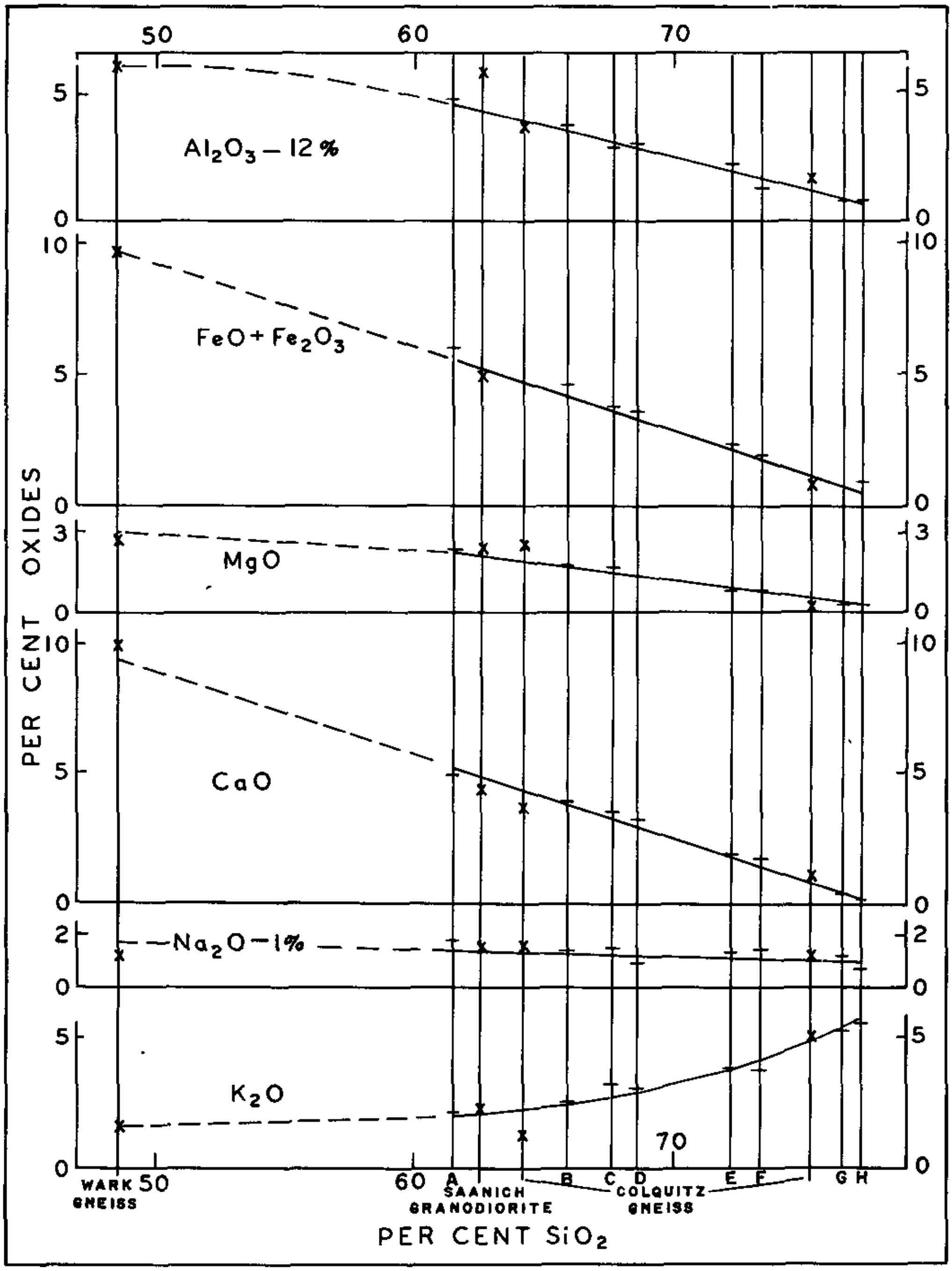

Figure 5. Variation diagram of chemical analyses of the Saanich granodiorite and related plutonic rocks on southern Vancouver Island.

that the Saanich granodiorite and the gneissic complexes are genetically related. The curves give an alkali-lime index—that is, a silica content at which $K_2O+Na_2O=CaO$ (Peacock, 1931)—between 59 and 60.

CHEMICAL ANALYSES AND NORMS OF SAANICH GRANODIORITE

CHEMICAL ANALYSES

	A	B	C	D	E	F	G	H
SiO_2	61.38	65.68	67.46	68.46	72.00	73.16	76.44	76.96
TiO_2	0.45	0.32	0.31	0.26	0.16	0.16	0.06	0.07
Al_2O_3	16.73	15.56	14.85	14.99	14.30	13.42	12.80	12.85
Fe_2O_3	2.85	2.04	1.59	1.56	1.01	0.83	0.46	0.40
FeO	3.21	2.59	2.15	2.11	1.27	1.14	0.31	0.40
MnO	0.14	0.12	0.11	0.08	0.06	0.05	0.01	0.02
MgO	2.43	1.78	1.61	1.43	0.78	0.87	0.23	0.22
CaO	4.92	3.94	3.52	3.18	1.98	1.80	0.50	0.24
BaO	0.11	0.09	0.11	0.07	0.13	0.15	0.30	0.06
Na_2O	3.71	3.37	3.32	2.92	3.25	3.44	3.15	2.68
K_2O	2.15	2.65	3.28	3.07	3.98	3.77	5.45	5.64
P_2O_5	0.20	0.14	0.13	0.11	0.06	0.06	0.02	0.03
H_2O+	1.60	1.78	1.54	1.46	1.09	1.32	0.42	0.64
H_2O-	0.16	0.16	0.14	0.19	0.08	0.17	0.08	0.08
CO_2	0.08	0.18	0.07	0.09	0.15	0.05	*Nil*	0.10
Totals	100.12	100.40	100.19	99.98	100.30	100.39	100.23	100.39

Analyses made in laboratory of British Columbia Department of Mines, G. C. B. Cave, Chief Analyst.

NORMS

	A	B	C	D	E	F	G	H
Quartz	16.68	24.72	25.38	30.24	32.46	33.72	35.76	39.18
Orthoclase	12.79	15.57	20.36	18.35	23.35	22.24	32.25	33.36
Albite	31.44	28.30	27.67	24.63	27.25	28.82	26.72	22.53
Anorthite	22.51	17.51	16.12	14.46	9.17	8.90	3.06	0.83
Corundum	—	0.71	—	1.53	1.33	0.41	0.51	2.00
Diopside	0.46	—	—	—	—	—	—	—
Hypersthene	8.38	7.17	6.24	5.75	3.22	2.33	0.60	0.63
Ilmenite	0.91	0.61	0.61	0.46	0.30	1.52	0.15	0.15
Magnetite	3.71	2.02	2.32	2.32	1.29	1.16	0.46	0.69
Apatite	0.34	0.34	0.32	0.34	—	—	—	—
Calcite	0.20	0.40	0.20	0.20	0.30	0.10	—	0.20
Water	2.76	1.94	1.68	1.65	1.17	1.49	0.50	0.72
Totals	100.18	99.29	100.90	99.93	99.84	100.69	100.01	100.29

A (Spec. 575)—Quartz diorite, west side of Cottonwood Creek 2 miles north of Cowichan Lake.
B (Spec. 434)—Granodiorite, 1,200 feet south of the top of Mount Buttle Peak Two, elevation 4,000 feet.
C (Spec. 601)—Granodiorite, elevation 2,950 feet, 3,000 feet southeast of the top of Mount Buttle Peak Two.
D (Spec. 437)—Granodiorite, elevation 3,800 feet, 2,500 feet east of the top of Mount Buttle.
E (Spec. 432)—Quartz monzonite, 300 feet southeast of top of Mount Buttle Peak Two.
F (Spec. 438)—Granite, 2,500 feet east of top of Mount Buttle Peak Two.
G (Spec. 439)—Aplogranite, 2,500 feet east of top of Mount Buttle Peak Two.
H (Spec. 428)—Aplogranite, 300 feet southeast of top of Mount Buttle Peak Two.

MINERALOGICAL COMPOSITIONS (WEIGHT PER CENT) OF CHEMICALLY ANALYSED SPECIMENS

	A	B	C	D	E	F	G	H
Quartz	19.5	28.6	28.3	27.2	36.7	34.1	36.9	36.5
Potash feldspar	4.2	13.0	12.4	15.9	17.5	29.0	44.6	34.5
Plagioclase	55.7	47.3	46.2	47.8	40.6	33.3	17.1	27.7
Biotite	6.2	5.2	6.7	5.5	4.0	3.3	0.6	1.2
Hornblende	12.7	4.3	4.7	2.6	—	—	—	—
Accessories[1]	1.7	1.5	1.7	0.9	1.2	0.3	0.8	+
Per cent anorthite in plagioclase—								
Cores[2]	50	45	55	50	32	5–30	5–20	5–25
Edges[2]	20	20	20	20	20			
From norm	42	38	37	37	25	24	10	4

[1] Mainly magnetite.
[2] Determined by Rittmann's zone method.

Metamorphism Related to the Granodiorite

Volcanic and sedimentary rocks commonly as far as 50 feet from masses of Saanich granodiorite have undergone changes genetically related to the granodiorite. Contact metamorphism has involved recrystallization and the development of minerals characteristic of the granodiorite. Farther from granitic masses, volcanics and sediments have been altered, generally to hornblende-bearing rocks, and their original textures and structures have been modified, but not completely obliterated, by recrystallization. This regional metamorphism appears to be spatially related, and may also be genetically related to the granodiorite. Both the contact and the regional types of metamorphism are described here as metamorphism associated with the plutonic activity.

Regional Metamorphism of Basic Rocks.—The Franklin Creek volcanics (*see* p. 20) and amygdaloidal basalts of the Sicker group (*see* p. 13), because of their relatively uniform composition, give the most reliable record of the nature and extent of regional metamorphism. In both these rock types, the most widespread change has been the development of light-green hornblende. Hornblende gives a greenish cast to hand specimens, and in thin sections appears as fine needles, or coarser crystals with ragged, fibrous edges. In non-porphyritic rocks it characteristically forms rims separating pyroxene from plagioclase crystals or veinlets in pyroxene crystals. Under the microscope separate rims and veinlets in one pyroxene extinguish together. Where hornblende is more abundant, it forms pseudomorphs with or without cores of pyroxene as well as fine needles in plagioclase. In porphyritic rocks, phenocrysts are commonly hornblende with cores of pyroxene, and the groundmass is crowded with fine hornblende needles. Hornblende in the regionally metamorphosed rocks is lighter green than ragged hornblende in the volcanics near granodiorite on Mount Buttle (*see* p. 39). The light-green hornblende is probably actinolitic, but its optic properties* vary from place to place and in several specimens are not significantly different from those of the darker-green hornblende.

This alteration of pyroxene to hornblende is locally accompanied by an alteration of plagioclase to clinozoisite. In thin sections of diabasic rocks containing relatively small amounts of hornblende, centres of labradorite laths are commonly crowded with minute crystals of high relief, the anomalous blue interference colours of which indicate that they are clinozoisite. The proportion of clinozoisite generally is not great (*see* table on p. 21), and the labradorite is otherwise unchanged. Even in rocks in which nearly all of the pyroxene is changed to hornblende and much of the plagioclase is replaced by clinozoisite, the remaining plagioclase is clear labradorite.

Although no extensive work has been done on the regional distribution of the hornblende-bearing rocks, specimen study suggests that hornblende is more widespread in the eastern part of the area, where numerous masses of granodiorite are exposed, than in the western part, where distances between granodiorite masses are great. The Franklin Creek volcanics along the Nitinat River and at the west end of Cowichan Lake, for example, contain only minor amounts of chlorite, epidote, or biotite, but no hornblende; whereas near Mount Whymper and El Capitan, as well as on the peninsula at the east end of Cowichan Lake, hornblende is a characteristic and locally abundant mineral. About the same regional distribution of hornblende has been noted in basalts of the Sicker group; none was seen in specimens from the Nitinat River region, but in rocks north of Cowichan Lake and east of Shaw Creek, hornblende is present. Northwest of the Cowichan Lake area, in the China Creek area, and near Horne Lake, where masses of granodiorite are more widely spaced than in the Cowichan Lake area, Franklin Creek volcanics contain no hornblende and rare chlorite or epidote. To the east in the Duncan and Saanich areas, granodiorite occurs as large and small stocks, and many of the volcanic rocks contain secondary hornblende (Clapp and Cooke, 1917, p. 101). The distribution of hornblende-bearing rocks suggests that the hornblende is genetically related to the

* The maximum refractive index on cleavage fragments and $2V_X$ range from 1.65 and 73 degrees to 1.67 and 67 degrees. Corresponding properties of the darker-green hornblende are 1.67 and 70 degrees.

granodiorite. This suggestion is strengthened by the fact that within a few hundred feet of some masses of granodiorite the amount of hornblende in the volcanic rocks is higher than in similar rocks at greater distances from the granodiorite.

Contact Metamorphism of Basic Igneous Rocks.—Basalts in contact with masses of Saanich granodiorite have been studied at two localities—on Mount Buttle and about a mile north of Youbou. On Mount Buttle the basalts are exposed between the west side of Peak Three and the top of Peak Two, conformably overlying the thin-bedded cherty sediments to the east. They are porphyritic, and near Peak Three, amygdaloidal. On Peak Two they are locally fragmental but of the same composition as to the east. Because of their similarity to other flow rocks of the Sicker group, all are regarded as flows. The volcanic rocks form a capping 200 to 400 feet thick that overlies the granodiorite and is in sharp contact with it (*see* Fig. 3).

All the volcanic rocks contain large amounts of hornblende and minor amounts of sericite, epidote, and biotite, but relicts of original minerals and textures are preserved right to the granodiorite contact. In thin sections, the volcanics are seen to consist of highly altered phenocrysts of augite and plagioclase in an aphanitic groundmass. Much of the groundmass and parts of the plagioclase phenocrysts are replaced by fine needles of hornblende, and pyroxene phenocrysts are replaced by larger hornblende crystals with ragged and fibrous edges. The hornblende is partly altered to biotite, and this alteration is more extensive a few feet above the granodiorite than it is 200 to 300 feet above the granodiorite. Plagioclase phenocrysts contain fine epidote, hornblende, and sericite and, therefore, are difficult to identify. In two specimens collected a few inches from the granodiorite, plagioclase phenocrysts were identified as andesine. In a specimen from about 200 feet above the granodiorite, plagioclase phenocrysts appear to have been recrystallized to a fine aggregate of another plagioclase, possibly oligoclase. Accessory minerals in the volcanic rocks include magnetite and locally relatively abundant apatite. Amygdules are well defined and undeformed, and contain granular aggregates of fine quartz, calcite, epidote, hornblende, and locally garnet. A chemical analysis of specimen 415, collected 14 inches above the contact between aplogranite and the volcanics on the north side of the ridge between Peaks Two and Three, is given on page 40.

About a mile north of Youbou, on the steep east slope of Widow Creek, porphyritic amygdaloidal rocks of the Sicker group, very similar to those described above, are in contact with the same mass of granodiorite as is exposed on Mount Buttle. They form a southeasterly trending band about 1,000 feet wide which is transected by the granodiorite between elevations of about 2,200 and 3,000 feet. These rocks are believed to be flows conformable with the steep northeasterly dipping sediments near by, but primary structures that would confirm their origin or attitude have not been recognized.

Microscopic examination reveals that the rocks contain the same minerals and exhibit the same textures and structures as those on Mount Buttle. Rocks within about 700 feet of the granodiorite contain 40 to 60 per cent hornblende, but within this zone there appears to be no systematic increase in the hornblende or biotite content toward the granodiorite. Plagioclase phenocrysts, identified in one section as andesine, contain sericite, epidote, and hornblende, in amounts which vary from place to place. These latter minerals, together with fine quartz and small amounts of a fine colourless mineral (probably plagioclase), comprise the groundmass. Magnetite and apatite are common accessories, and amygdules contain quartz, calcite, and epidote.

Low on the hillside the contact of these rocks with the granodiorite is relatively sharp, but higher up it appears to be gradational. Below elevations of about 2,500 feet the granodiorite appears normal, and the contacts, although covered by overburden, can be located within a few tens of feet. At higher elevations the granitic rocks contain more mafic minerals than at lower elevations and the volcanic rocks near the granitic mass have been recrystallized. Above about 2,700 feet no definite contacts between granitic rocks and volcanics have been recognized. Although relatively sharp contacts may exist, the mafic-rich granitic rocks appear to grade into recrystallized volcanics by a gradual change in composition and texture. The transitional rock types resemble massive diorite, but at places vague gneissic bands are present, and at others amygdules indicate the volcanic origin of some of the rocks.

CHEMICAL ANALYSES OF VOLCANIC ROCKS NEAR THE SAANICH GRANODIORITE

	5349	415	5358	575
SiO_2	50.08	46.56	50.92	61.38
Al_2O_3	12.20	13.74	14.97	16.73
Fe_2O_3	3.39	4.61	3.53	2.83
FeO	5.33	5.65	4.92	3.21
MgO	9.83	9.14	7.69	2.43
CaO	11.78	11.92	9.18	4.92
Na_2O	2.42	2.38	2.35	3.71
K_2O	0.88	1.35	1.76	2.15
H_2O-	0.61	0.80	0.78	0.16
H_2O+	2.46	2.98	2.78	1.60
Specific gravity	3.01	2.99	2.86	2.74

Analyses made in laboratory of British Columbia Department of Mines, G. C. B. Cave, Chief Analyst.
5349—Altered porphyritic amygdaloidal basalt, 1 mile north of Youbou, east side of Widow Creek, elevation 2,150 feet.
415—Altered porphyritic amygdaloidal basalt, north slope of ridge between Peaks Two and Three of Mount Buttle.
5358—Recrystallized amygdaloidal basalt, 1 mile north of Youbou, east slope of Widow Creek, elevation 3,000 feet.
575—Quartz diorite, west side Cottonwood Creek about 2 miles north of Cowichan Lake.

CALCULATED GAINS (+) AND LOSSES (—) WHEN 100 CUBIC CENTIMETRES OF ROCK OF THE COMPOSITION OF 5349 IS CONVERTED TO 100 CUBIC CENTIMETRES OF ROCK OF THE COMPOSITION OF 5358

SiO_2	—5.11	CaO	—9.21
Al_2O_3	+6.09	Na_2O	—0.56
Fe_2O_3+FeO	+0.12	K_2O	+2.28
MgO	—7.60		

MODAL ANALYSES OF SPECIMENS FROM THE EAST SLOPE OF WIDOW CREEK ABOUT A MILE NORTH OF YOUBOU

Specimen No.	Modal Analyses (Weight per Cent)							Per Cent Anorthite in Plagioclase[2]	
	Quartz	Potash Feldspar	Plagioclase	Biotite	Hornblende	Pyroxene	Accessories[1]	Cores of Crystals	Edges of Crystals
Quartz Diorite									
575	19.5	4.2	55.7	6.2	12.7	——	1.7	50	20
536	23.1	4.5	49.8	7.7	14.0	——	0.9	47	26
537	19.8	3.0	56.2	7.1	11.3	——	2.8	47	29
539	19.6	7.3	52.2	6.1	12.6	——	2.2	55	28
Transitional Types									
540	12.7	1.9	58.6	7.2	17.0	——	2.6	55	30
542	2.2	——	51.9	4.7	26.1	8.2	6.8	53	45
544B	7.1	——	63.8	4.8	23.8	0.5	+	53	30
5358	——	0.8	37.9	——	59.9	1.3	+	47	47
Volcanics									
543[3]	——	——	40	——	27	24	+	n.d.	n.d.
5349	——	——	27[4]	——	55	18	+	n.d.	n.d.

[1] Mainly magnetite.
[2] Determined by Rittmann's zone method (Emmons, 1943, p. 121); five or six crystals determined in each thin section.
[3] Contains 8 per cent chlorite.
[4] Includes all felsic minerals in the groundmass.
n.d.—not determined.

Localities

575, 536, 537, 539, and 540 correspond respectively to localities A, 6, 7, 8, and 9 of Figure 2.
542—Elevation 2,950 feet, centre of zone of recrystallization.
544B—Elevation 3,550 feet, south side of ridge about a mile north of Youbou.
5358—Elevation 3,000 feet, north side of zone of recrystallization.
543—Elevation 2,950 feet, north of granitized zone.
5349—Elevation 2,150 feet, 200 to 300 feet north of granodiorite.

The composition of the normal granodiorite and of some of the transitional types is indicated by modal analyses listed on page 40. Specimens 536, 537, and 539 are of quartz diorite from below elevations of 2,700 feet on the east slope of Widow Creek. They are characteristic of an intermediate to mafic facies of the Saanich granodiorite. Specimens 540, 542, 544, and 5358 are fine- to medium-grained rocks regarded as transitional between the quartz diorite and the volcanics. Inspection of the table shows that the quartz diorite contains more quartz, potash feldspar, and biotite and less hornblende than the transitional types. Augite, as cores of hornblende crystals in the transitional types, was not found in the quartz diorite. These few analyses, together with field observations, suggest that there is a fairly gradual change from the relatively uniform composition of the quartz diorite to the transitional rock types of undoubted volcanic origin. The mineralogical composition of the volcanic rocks is difficult to determine because of the fine grain size of many of the minerals. Hornblende has been estimated to comprise 40 to 60 per cent of the volcanic rocks, pyroxene less than 25 per cent, plagioclase 15 to 25 per cent, and sericite, epidote, chlorite, and biotite occur in varying amounts up to about 10 per cent.

Differences in composition between the quartz diorite, transitional types, and altered volcanics are accompanied by differences in texture. The normal quartz diorite has a medium-grained hypidiomorphic texture, the transitional types have fine- to medium-grained allotriomorphic textures, and the altered volcanics retain their porphyritic texture, though it may be masked by excessive amounts of hornblende. In the Saanich granodiorite, potash feldspar poikilitically encloses crystals of plagioclase, hornblende, and biotite. In the transitional rock types in which it is a minor constituent, potash feldspar is interstitial, but maintains a tendency to surround other crystals. Areas of thin sections 2 or 3 millimetres in diameter may contain hornblende or plagioclase crystals in a "matrix" of potash feldspar that extinguishes as a single crystal. Potash feldspar in all rock types is microperthitic.

Differences in the chemical composition of three selected specimens representing the quartz diorite, a transitional type, and the least altered volcanics are shown by the analyses listed in the table on page 40. In this table, specimen 575 is from the same body of granodiorite as that under consideration, but was collected about a mile west of the Widow Creek locality. General similarities in the mode of specimen 575 and of the quartz diorite (specimens 536, 537, and 539 of table on page 40) suggest that the chemical compositions of the quartz diorite low on the east slope of Widow Creek are about the same as that of specimen 575. Specimen 5358 is a transitional type, a recrystallized volcanic containing amygdules.* Specimen 5349 is one of the least altered amygdaloidal volcanics from an elevation of about 2,150 feet, 200 feet north of the granodiorite.

Sample 5358, typical of the least altered transitional rock type, was selected for chemical analysis because it appears to have been derived from a rock of the composition of sample 5349. If it be assumed that both had the same original composition and that one was derived from the other without change in volume, changes in oxide content are represented by gains and losses shown on page 40. They indicate that the transitional type gained potash and alumina, and lost silica, lime, and magnesia. Since specimen 5358 is one of the least recrystallized transitional types and specimen 5349 is a partly altered volcanic rock, the calculated changes represent only part of the chemical changes involved in the transformation of altered volcanics to the more completely recrystallized transitional types. Most of the transitional types contain more quartz and less mafics than the volcanics and specimen 5358. In chemical composition they probably lie between the composition of specimen 5358 and that of the quartz diorite (575). If this be correct, in addition to the changes suggested above, the volcanics in the contact zone may have gained silica and lost iron.

* Material as free as possible from amygdules was selected for chemical analysis.

In summary, the basaltic rocks appear to have undergone two types of metamorphism: (1) The development of hornblende, epidote minerals and minor biotite with the preservation of original textures and structures until masked by secondary minerals; and (2) the development of minerals similar to those in the granodiorite with recrystallization tending to give granitic textures. The first is the more widespread change, whereas the second appears to be superimposed on the first and restricted to zones adjacent to the granodiorite. Both types of metamorphism occur at the Widow Creek locality north of Youbou and probably also near most granodiorite contacts. On Mount Buttle the second or contact type is missing.

Regional Metamorphism of the Sedimentary Rocks.—Although no systematic study of the metamorphism of the pre-granitic sedimentary rocks has been made, about twenty-five thin sections of fine-grained clastic sediments representative of various facies of both the Sicker sediments and sediments associated with the Sutton limestone have been studied. Fine clastic sediments in the contact zone of the Saanich granodiorite exposed in McKay Creek about 2 miles north of Cowichan Lake have been examined in some detail, and slightly different sediments in contact zones on Mount Buttle have received less attention. Skarn deposits probably resulting from contact metamorphism of calcareous sediments occur at two localities in the Cowichan Lake area.

Pre-granitic clastic sediments have not been highly metamorphosed except near masses of granodiorite. In general they are blocky and not schistose. In most of the feldspathic tuffs and tuffaceous greywackes, the original clastic grains can be seen easily in thin section. Biotite, chlorite, epidote, and hornblende are present in all the clastic sediments, but in general amount to less than 10 per cent of the rock. Fragments of basic igneous rocks; clastic crystals mainly of andesine, hornblende, or pyroxene; and a siliceous or argillaceous matrix are the main constituents.

In some of these rocks biotite is the predominant secondary mineral, and in others hornblende and epidote predominate. Biotite, in small orange-brown to colourless flakes, and minor sericite occur in rocks in which primary mafic minerals are scarce. Biotite is present in the matrix of feldspathic crystal tuffs and in both fragments and matrix in sediments that contain rock fragments. Fibrous light-green hornblende and granular epidote with minor chlorite and sericite are encountered in rocks in which mafic silicates and magnetite are present. Epidote is commonly found in the matrix, and hornblende as an alteration product of pyroxene. Hornblende is commonly altered to chlorite, and in one thin section appears to be altered to small light-brown flakes of biotite.

The following observations suggest that the biotite, hornblende, and epidote are products of regional metamorphism, and probably related to the Saanich granodiorite: (1) The hornblende-epidote alteration of the more basic sediments, many of which are andesitic in composition, resembles in some respects the regional metamorphism of the Sicker basalts; (2) in contact zones of the Saanich granodiorite, hornblende is a common metamorphic mineral in some of the clastic sediments; (3) field observations suggest that in some sediments biotite is more abundant within about a quarter of a mile of granodiorite than farther away. This is particularly noticeable on the ridge between Cottonwood and the head of Wardroper Creek, and south of Chemainus River on the lower north and northwest slopes of Mount Franklin.

Contact Metamorphism of Mafic Clastic Sediments.—A contact between thin-bedded sediments of the Sicker group and the Saanich granodiorite is well exposed in McKay Creek about 2 miles north of Cowichan Lake. A field sketch of the outcrops on the east side of McKay Creek at this contact is shown in Figure 6. The main mass of granodiorite lies north of the outcrops shown, and thin-bedded sediments form a narrow band dipping steeply southwest and extending southeastward beneath valley fill beyond the most southerly outcrop shown. The regional strike of the sediments is southeastward, but near the granodiorite it is northeast, and consequently the sediments exposed represent approximately one horizon and were probably lithologically similar before metamorphism.

Downstream from the outcrops sketched, across the strike of the sediments, rock types change in composition and texture. This together with the fact that the sediments are not exposed away from the banks of the creek make it impossible to study them beyond the contact zone.

The main mass of granodiorite is in sharp contact with grey hornfelsic rocks at the north edge of the most northerly outcrop of Figure 6. The granodiorite has a leucocratic selvage an eighth to a quarter of an inch wide. Tapering granitic dykes a few inches wide and 1 or 2 feet long extend from the granodiorite into the hornfels, and they are leucocratic near the sharp ends farthest from the granodiorite. The band of massive hornfels is of variable width and at places is absent. Away from the granodiorite, it grades into a zone of migmatite in which subparallel bands and lenses of granitic rock a fraction of an inch to several inches thick are found in a mottled, vaguely banded hornfels. At one place a body of massive granodiorite cuts irregularly across the migmatite. The granitic part of the migmatite is similar to the main mass of granodiorite.

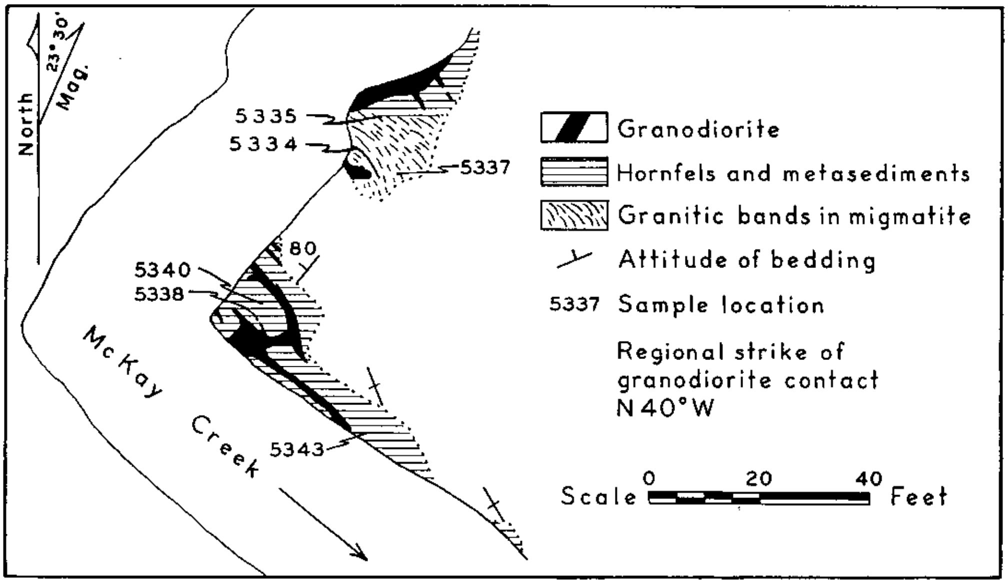

Figure 6. Sketch-map of outcrops near the granodiorite contact on the east bank of McKay Creek.

The hornfelsic part of the migmatite is grey and at places vaguely banded parallel to the granitic bands. Thin sections exhibit a granoblastic texture. Equidimensional anhedral and subhedral grains of quartz, sodic andesine, biotite, and hornblende are the main constituents. Most crystals are about 0.3 millimetre across, but larger crystals of hornblende and plagioclase are fairly common. Abundant rounded inclusions of quartz in these larger crystals give them a pronounced sieve texture characteristic of all hornfelsic rocks in this contact zone.

In the southern outcrops of the sketch (*see* Fig. 6) granodiorite is exposed in well-defined, irregular, branching dykes 1 to 2 feet wide (*see* Plate XII). Small branches terminate as thin wedge-shaped masses, the sharp ends of which are more leucocratic than the normal granodiorite. The leucocratic terminations are similar to those of small dykes protruding from the main mass of granodiorite in the outcrop to the north. Most of the dykes are normal granodiorite.

The green metasediments cut by the dykes locally exhibit poor bedding. In thin section they appear finer grained than the hornfels close to the granodiorite. Vague metacrysts of hornblende and poorly twinned plagioclase are surrounded by and enclose crystals of quartz, biotite, and hornblende, one or two tenths of a millimetre across. In one thin section the original texture of the rock can be inferred from the presence of areas relatively free from hornblende or biotite that show distinctive porphyritic or mosaic textures, and are surrounded by areas rich in hornblende and biotite. Areas with distinctive textures are interpreted as fragments of porphyritic volcanics and cherty sediments, and suggest that the rocks were originally clastic sediments composed of rock (and mineral) fragments 1 to 2 millimetres across.

Modal analyses of two thin sections of metasediments, three of hornfels, and three granodiorites from near the contact in McKay Creek are listed in the table below. Several significant differences in mineralogical composition between the rock types are obvious. The metasediments contain more hornblende and biotite and less potash feldspar, quartz, and generally less plagioclase than the hornfels and near-by granodiorite.

The chemical meaning of these mineralogical differences is fairly obvious for a few constituents but uncertain for most. The problem of obtaining chemical data from mineralogical analyses is made difficult by the unknown and variable compositions of many of the minerals. Interpretation of the analyses is uncertain because the relatively few samples examined may not be typical of the metamorphic rocks, or the metamorphic rocks may not have been derived from sediments of uniform composition. However, the following general observations seem justified.

The higher proportion of hornblende and in general of biotite in the metasediments as compared with the hornfels indicates a higher proportion of iron and magnesia in the former than in the latter since these two minerals, together with minor relatively constant amounts of magnetite, pyrite, epidote, and chlorite, contain essentially all the iron and magnesia in the rocks. In the modal analyses listed below the hornblende content increases regularly, and the biotite content less regularly, away from the granodiorite contact. The iron and magnesia content of equivalent unmetamorphosed sediments is uncertain, but none of the fine clastic sediments studied in thin sections contain as high a proportion of mafic minerals as the metasediments 50 to 60 feet from the granodiorite. Hence the metasediments are probably richer in iron and magnesia than sediments from which they were derived.

MODAL ANALYSES OF SPECIMENS NEAR THE GRANODIORITE CONTACT IN McKAY CREEK

Specimen No.	Rock Type	Modal Analyses (Weight per Cent)						Chemical Estimates[2]	
		Quartz	Potash Feldspar	Plagioclase	Biotite	Hornblende	Accessories[1]	K_2O	SiO_2
457	Quartz diorite, main body	26.4	9.6	50.2	4.8	7.1	1.9	2.2	69.5
5334	Quartz diorite, migmatite zone	25.4	9.0	46.4	6.5	9.7	3.0	2.2	67.3
5334A[3, 4]	Hornfels, migmatite zone	27.9	0.5	33.2	19.2	17.2	1.4[5]	2.3	64.1
5335	Hornfels, migmatite zone	65.6	1.5	13.3	1.7	15.7	1.5	0.4	81.6
5337	Hornfels, migmatite zone	38.2	0.3	31.4	13.9	15.3	0.9	1.5	70.0
5340	Metasediment	24.8	0.3	14.8	11.4	47.5	1.2	1.3	57.0
5343	Metasediment	24.1	+	14.4	19.2	40.4	1.9	2.1	56.5
5338	Leucogranite	51.2	4.6	43.2	1.0	—	+	n.d.	n.d.

[1] Mainly magnetite.
[2] Based on the oxide content of minerals listed in Johannsen (1931, Table XLIV).
[3] Contains 0.1 per cent epidote.
[4] Contains 0.7 per cent epidote.
[5] Mainly pyrite.
n.d.—not determined.

Principal oxides other than iron and magnesia occur in several minerals. The proportions of the oxides do not vary sympathetically with these minerals, and variations in the chemical composition from one sample to another can be obtained from the modal analyses only by calculation. In such calculations, assumptions must be made regarding the chemical compositions of several of the minerals, and consequently the results will show only relatively large differences in proportions of the principal oxides. In addition, some of the minerals may vary slightly in composition from one sample to another. Estimates of the potash and silica content of specimens from near the granodiorite contact in McKay Creek based on modal analyses are listed on page 44. These estimates only approximate the true oxide content of the rocks, but give a basis for comparison of one sample with another. Differences in silica content of the specimens analysed may be significant even though compositions of several silicates must be assumed. If so the hornfels adjacent to the granodiorite contains as much, if not more, silica than the granodiorite, whereas the metasediments farther away contain significantly less silica. Estimates of potash indicate that if there are significant differences in the potash content of the rocks near the contact, this method of sampling and analysis is not refined enough to detect them. Similar results were obtained for estimates of the soda, lime, and alumina content, and these have not been tabulated.

The metamorphism of these mafic clastic sediments appears to parallel the metamorphism of the mafic volcanics to some extent. Both have undergone a low grade of regional metamorphism that has resulted in the development of ragged hornblende and minor amounts of epidote minerals. In the contact zone on McKay Creek the metamorphosed sediments have undergone changes comparable to those in the transitional rock types at the Widow Creek locality (*see* p. 41). The proportion of mafic constituents appears to culminate 50 to 60 feet from the granodiorite contact. Closer to the granodiorite the sediments are recrystallized and the new minerals developed in them are characteristic minerals of the granodiorite.

Contact Metamorphism of Other Types of Sediments.—On the east slope of Peak Three of Mount Buttle, thin-bedded sediments of the Sicker group are in contact with granodiorite. The sediments include cherty and feldspathic tuffs and fine-grained argillaceous or tuffaceous sediments. The contact is well exposed at an elevation of about 1,900 feet in an eastward-flowing tributary of McKay Creek east of the top of Peak Three. The cherty rocks have been recrystallized near the contact without the formation of new minerals, whereas the impure sediments have been converted to hornfels similar to that exposed in McKay Creek at the granodiorite contact described above. Bedding is well preserved, and the rocks are blocky and not schistose.

Microscopic studies indicate that the cherty sediments are composed mainly of quartz, with less than 5 per cent biotite, plagioclase, hornblende, epidote, and magnetite in minute crystals. The rocks have a mosaic texture and range in grain size from about 0.2 millimetre 100 feet from the granodiorite to about 2 millimetres 15 to 20 feet from the granodiorite. Tuffaceous sediments interbedded with the cherts contain ragged crystals of green hornblende, small flakes of biotite, and small amounts of sericite and chlorite. Relict clastic crystals of plagioclase in a mosaic of fine-grained quartz indicate that the sediments were originally feldspathic cherty tuffs. At the granodiorite contact the sediments contain about equal amounts of finely crystalline hornblende, biotite, plagioclase, and quartz and appear to have been entirely recrystallized to hornfels. The granodiorite at the contact contains a relatively high proportion of mafic minerals, but is otherwise similar to the normal granodiorite.

Limestone and calcareous sediments in contact with the Saanich granodiorite are not known to be exposed in the Cowichan Lake area. Deposits of skarn typical of metamorphosed calcareous rocks are found at two places, and these localities are described in Chapter III. In general aspect the skarn deposits resemble those resulting from contact metamorphism, and in the Cowichan Lake area they are thought to be genetically related to the Saanich granodiorite, but this has not been proved.

Inclusions in the Granodiorite

The granodiorite exhibits no linear or planar structures, but contains rounded mafic inclusions ranging from about an inch to several inches in diameter. They are present in most outcrops in fairly constant proportions, comprising probably less than 2 per cent of the volume of the rock (*see* Plate XI). Locally within 50 feet of contacts with the older rocks the proportion increases. Most of the inclusions have vague outlines and are so nearly equidimensional that the orientation of their long axes can rarely be measured, and no preferred orientation is apparent. In addition to these small rounded inclusions, several larger inclusions as much as 6 feet across have been seen. Two of these, exposed in Wardroper Creek, are poorly banded and resemble thin-bedded sediments of the Sicker group. The others are massive fine-grained hornblendic rocks. Very much larger inclusions, measuring several tens of feet across, occur locally. Three of the largest are: (1) On the ridge between Cottonwood and Wardroper Creeks about 2 miles from Cowichan Lake; (2) near the head of the east fork of McKay Creek; and (3) between elevations of 2,500 and 3,000 feet on the southwest side of the cirque southeast of Mount Buttle. They all lie within a few hundred feet of the edge of the granodiorite mass that encloses them and at some place may be connected with near-by wallrocks. The large inclusions resemble volcanic and sedimentary rocks rich in hornblende, but they have not been studied petrographically.

The small inclusions studied in thin section are seen to be made up of variable proportions of the same minerals as the surrounding granodiorite. Hornblende and plagioclase are the main constituents, whereas quartz and potash-feldspar are minor, and locally absent, as indicated by the mineralogical analyses listed below. Plagioclase is zoned andesine, locally intensely altered to sericite and epidote minerals. Many of the crystals are subhedral, but where surrounded by potash feldspar the plagioclase crystals have scalloped and, at places, myrmekitic edges. Potash feldspar, largely orthoclase-microperthite, shows the same tendency to enclose other minerals poikilitically as it does in the granodiorite and in contact metamorphosed wallrocks. Crystals of potash feldspar in some inclusions are as much as half a centimetre across. Magnetite is commonly more abundant in the inclusions than in the adjacent granodiorite, but in general this is not true of the other accessories, apatite, zircon, and sphene. Many of the inclusions have a marginal zone a few millimetres wide in which quartz and potash feldspar are present in greater proportion than in the centre, but otherwise most inclusions are uniform in texture and composition throughout. A few, however, contain irregular masses relatively richer in felsic minerals than other parts of the same inclusion.

The inclusions are regarded as fragments of the volcanic and sedimentary wallrocks for the following reasons: (1) They increase in number within about 100 feet of the contacts of the granodiorite bodies; (2) large inclusions have sedimentary and volcanic structures and textures; and (3) small inclusions resemble in many respects rocks in zones of contact metamorphism around the margins of the granodiorite.

MINERALOGICAL ANALYSES OF SMALL INCLUSIONS IN SAANICH GRANODIORITE
(WEIGHT PER CENT)

Specimen No.	Quartz	Potash Feldspar	Plagioclase	Biotite	Hornblende	Accessories[1]
120	......	26.9	36.5	4.4	28.3	3.9
449B	......	24.3	46.6	2.4	23.7	3.0
5346	2.2	3.2	59.9	7.3	23.5	3.9
494	4.2	7.2	49.8	11.8	23.3	3.7
220A	8.6	0.5	59.6	11.6	16.0	3.7
5346A	8.8	+	59.8	11.3	13.9	6.6

[1] Mainly magnetite.

Localities

120—North slope of Buttle Mountain Peak Three.
449B—Float, McKay Creek.
5346—McKay Creek, 2¼ miles north of Cowichan Lake.
494—Southwest fork of Nitinat River.
220A—2½ miles northwest of Lake Cowichan.
5346A—Float, McKay Creek.

Discussion

Features of the Saanich granodiorite described above have been observed in reconnaissance mapping in the Cowichan Lake area and in laboratory study of a number of specimens. In the following the genetic significance of some of the principal features is discussed.

Magmatic Intrusion and Replacement. — Although clear-cut evidence that the Saanich granodiorite has formed by crystallization of magma has not been discovered, the weight of the evidence favours a magmatic origin and not an origin by the transformation of the volcanic and sedimentary rocks to granodiorite. The following observations are considered significant:—

(1) Dykes in the contact zone in McKay Creek (*see* p. 29) display features that provide the most conclusive evidence for magmatic intrusion. As noted previously, however (*see* p. 29), the evidence at this locality is not beyond question. The general dyke-like form of the plutons and the fact that they cut across complex structures in the older rocks might be regarded as evidence of magmatic intrusion. Similar features, however, could have developed from a non-selective structurally controlled process of replacement.

(2) Variations in the composition of the granodiorite are not related to variations in the composition of the wallrocks. Instead there appear to be regional changes in composition, some of which are related to the form of the granodiorite masses. The most significant change in composition is on Mount Buttle, where the aplogranitic facies occurs above the granodiorite as protrusions into the volcanic roof. The facies appears to be related to the form of the pluton and not to the composition of the wallrock. In addition, the variation diagram (*see* Fig. 5) can be interpreted to suggest that magmatic processes have played a part in the development of the aplogranitic facies. It may also be significant that modal analyses in Figure 4 form a band across the diagram that follows approximately the boundary curve between the quartz and feldspar fields in the experimentally investigated system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 (Schairer, 1950).

(3) Some features of the mafic inclusions suggest that they have been rotated possibly by movement of magma. The most convincing occurrence of this sort is on the east slope of Peak Three of Mount Buttle at an elevation of about 1,900 feet. Two angular inclusions about a foot long and a few inches wide occur in the granodiorite close to its contact with thin-bedded sediments. The inclusions are not banded and are exposed only in a horizontal plane, but their long axes make angles of 45 to 60 degrees with the strike of the thin-bedded sediments a few feet from the contact. Other features of the mafic inclusions are also not in keeping with a replacement origin. If pre-existing rocks had been replaced to form granodiorite without significant change in volume or development of mobile material, the mafic inclusions would be expected to show some variation in abundance with the type of rock replaced, or to reflect old structures by some sort of preferred orientation. Neither of these features has been recognized.

Although the evidence is not beyond question, in the opinion of the writer it favours the development of the granodiorite by magmatic processes. Magmatic intrusion, however, was accompanied by replacement. Incomplete granitization of the wallrocks commonly to distances of about 30 feet and locally to distances of more than 100 feet from the granodiorite contact suggests migration of material into and out of the wallrocks. Mafic inclusions in the granodiorite are considered to be fragments of wallrock that have been recrystallized and replaced by minerals characteristic of the granodiorite. What quantity of wallrock the inclusions represent, and to what extent they modified the enclosing magma, is unknown.

Emplacement.—Bodies of granodiorite in the Cowichan Lake area are post-tectonic in relation to the Mesozoic orogeny that preceded the Upper Cretaceous. They cut across the folds in the older volcanic and sedimentary rocks and are themselves only slightly deformed. Emplacement appears to have been a passive process. Folds in the pre-granitic rocks do not reflect the form of the plutons. Instead the granodiorite appears to have been emplaced without more than slightly modifying pre-existing structures. The syncline in the Sicker sediments 2 miles north of Lake Cowichan, for example, is cut off abruptly by the granodiorite to the east, and close to the granodiorite the sediments are no more deformed than they are farther away. Similarly, on the top and east slope of Mount Buttle Peak Three, where sediments appear to form a northerly trending asymmetric anticline, the major structure is cut off by the granodiorite, but is otherwise unchanged. In addition, no marginal breccia zones have been recognized at any of the contacts. Hence the plutons do not appear to have deformed the volcanic and sedimentary rocks close to them. In general, however, plutonic masses in the Cowichan Lake area are more numerous where the older volcanic and sedimentary rocks are highly deformed. Along Shaw Creek and in the western part of the area where bodies of granodiorite are widely spaced, the folds are more open than they are in the eastern part of the area, where many masses of granodiorite are exposed. The folding may have controlled emplacement in some way, but does not appear to have been caused by emplacement, since the structures do not conform to the shapes of individual masses.

In detail the plutons are irregular even though in general they exhibit a pronounced elongation parallel to the fold axes in the older rocks. This elongate form may have been inherited in part from the older structural trends, but as the granodiorite was emplaced subsequent to the folding, some late controlling structures seem to have contributed to the form of the bodies. If such structures existed, they appear to have been non-stratigraphic, since the granodiorite does not follow beds or formations. They were probably not shear zones, for rocks along the strike and above masses of granodiorite are in general not schistose nor brecciated. In addition, pre-granitic rocks do not appear to have been displaced along old fault zones to which the granodiorite could be related. In the opinion of the writer, control of emplacement by incipient northwesterly trending tension fractures provides the most plausible explanation for the elongate form of the granodiorite plutons. Extension in a northeasterly direction perpendicular to the fold axes may have accompanied the beginnings of uplift, the relaxation of compressive stresses, or it may have resulted from some other cause.

It has been shown that one set of joints in the granitic rocks on Mount Buttle dips steeply and strikes northwestward parallel to the long axis of the plutonic mass (*see* p. 30). These joints probably developed soon after the crystallization of the granodiorite, since they contain quartz-sulphide veins thought to be genetically related to the granodiorite. The vuggy nature of the quartz veins and the absence of slickensides along the joint surface suggest the joints are tensional. Possibly structural conditions that existed before emplacement of the granodiorite continued during and after crystallization.

If emplacement involved magmatic intrusion, it was probably accompanied by stoping. Although there is no direct evidence that stoping has occurred, evidence has been presented (*see* p. 29) suggesting that the granodiorite dykes near the contact in McKay Creek are of magmatic origin. They lie parallel to the general trend of the granitic contact and may represent progressive fillings of incipient fractures behind partly stoped blocks. The wedge shape of many of the narrow dykes in this contact zone may be significant in indicating that fractures were progressively filled and widened. If stoping has occurred, except for the few large masses of recognizable wallrock surrounded by granodiorite, stoped blocks appear to have been transformed to the small rounded mafic inclusions. The increase in number of these inclusions toward the walls is in keeping with the suggestion that they are remnants of stoped blocks, but their uniform size and distribution away from the walls are features for which there is no obvious explanation.

Mafic Inclusions.—Reasons for regarding the small rounded mafic inclusions as fragments of the volcanic and sedimentary wallrocks have been given (*see* p. 46). Although relatively few specimens have been studied, the original rocks from which the inclusions were derived appear to have been recrystallized and changed so that they now contain minerals characteristic of the granodiorite. Theoretically this can be accomplished by magmatic assimilation. Siliceous masses enveloped during the early stages of crystallization of the magma from which the granodiorite formed might be partly melted and mechanically broken up. Since most of the wallrocks are more mafic than the granodiorite, most fragments would remain solid and be transformed by a process involving migrations of material. It is debatable whether this process can be regarded as one of assimilation or whether it is one of metasomatism. Occurrences of poikilitic potash feldspar in granodiorite suggest that potash metasomatism was active at least late in the crystallization history (*see* p. 50), but probably this process differed in time and scale from that which brought about most of the transformation of the inclusions. Whatever the process, the result appears to have been " acidification " of the inclusion, possibly by addition of silica, potash, and alumina, and " basification " of the magma. The high proportion of mafic minerals in small bodies of the granodiorite, in narrow parts of large dyke-like masses, and also near margins of larger masses may be attributed to basification of the magma by reaction with volcanics. Small inclusions present in all the granodiorite except the aplogranitic facies suggest that the entire original magma has been " basified " to some extent.

Aplogranitic Facies.—The aplogranitic facies is genetically related to the granodiorite. This conclusion is based on the fact that the granodiorite in the Mount Buttle area grades into aplogranite. In addition, chemical and mineralogical analyses plotted on Figures 4 and 5 suggest a genetic relationship between the granodiorite and the aplogranite. These diagrams may also be interpreted to mean that fractional crystallization has played a part in the formation of the aplogranite, but this conclusion is less certain than the first. On Mount Buttle the aplogranite is a roof facies of the granodiorite, and it has been suggested (*see* p. 32) that the masses of aplogranite north of Mount Buttle are also roof facies. This position beneath the roof and the gradational contact with the granodiorite precludes the possibility of the aplogranite being a separate late intrusion. The composition of the adjacent wallrocks does not appear to have directly affected the formation of the aplogranitic facies. No mafic inclusions have been seen in the aplogranite nor along the contact zone between aplogranite and granodiorite; either they did not exist or they have been completely assimilated. This latter suggestion seems unlikely, as the relative absence of mafic constituents is one of the outstanding features of the aplogranite, and locally within a foot of the contact between aplogranite and overlying volcanics biotite has formed in the aplogranite by contamination (*see* table on p. 35, No. 424).

The origin of the aplogranitic facies is problematical. Probably contamination of the magma from which the granodiorite formed, separation of a felsic differentiate, and late replacement of plagioclase by potash feldspar all contributed to the development of the aplogranitic facies. Granodiorite containing mafic inclusions probably crystallized from magma made more mafic by contamination. The aplogranitic facies shows little evidence of having been contaminated, but it seems unlikely that aplogranite represents the composition of the magma that crystallized after contamination to form granodiorite. More probably, contamination of the magma favoured the development of a late felsic differentiate. Mineralogical analyses show that the granodiorite in the Mount Buttle area contains more quartz and potash feldspar and a lower proportion of mafic minerals than the granodiorite in the same body to the east (*see* p. 34). There appear to be no abnormal concentrations of mafic minerals or plagioclase in the granodiorite adjacent to the aplogranitic facies. Consequently, development of the aplogranitic facies has involved more than an upward migration and simple removal of a late felsic differentiate from partly crystallized granodiorite magma. Probably reaction and replacement were modifying factors.

Poikilitic Potash Feldspar.—In the normal granodiorite relatively large crystals of potash feldspar enclose smaller crystals of biotite, hornblende, and plagioclase. In mafic facies the potash feldspar content is relatively low, but crystals of potash feldspar tend to enclose those of other minerals. Similar poikilitic potash feldspar occurs in mafic inclusions and also in recrystallized wallrocks near granodiorite contacts. In thin sections, plagioclase crystals in contact with or enclosed by potash feldspar appear corroded but in general retain shapes similar to those of the central zones of the plagioclase. Other minerals enclosed by potash feldspar retain their subhedral form and do not appear corroded. In the aplogranite, potash feldspar crystals do not enclose other crystals, but plagioclase in contact with orthoclase microperthite appears corroded. In the granodiorite, potash feldspar rarely encloses quartz crystals and hence quartz may have developed along with or later than potash feldspar.

Several occurrences in which identical feldspars have developed in granites, wallrocks, and inclusions have been summarized by Read (1944, p. 80), who regards this as one piece of evidence that " porphyritic granites are produced from sediments by an intensification of the feldspathization process " (Read, 1944, p. 86). However, Grout believes that " if there is a tendency to form large feldspars, the same large feldspars may grow in the border magma and in the wallrock or inclusion " (Grout, 1948, p. 49). In the Saanich granodiorite, potash feldspar developed late in the crystallization history and formed at least in part by replacement of plagioclase. In the wallrocks and inclusions, potash feldspar must have developed by replacement of pre-existing minerals and some material probably migrated into and out of the inclusion. These observations, although emphasizing the replacement origin of the potash feldspar, do not in the writer's opinion preclude the existence of magma.

Although development of potash feldspar appears to have been late in the formation of the granodiorite, it may have been relatively early in the formation of the aplogranite. As mentioned above, quartz probably developed along with or later than the potash feldspar, and as these two minerals comprise 60 to 70 per cent of the aplogranite, the tendency of potash feldspar in the aplogranite facies to enclose plagioclase would be minimized.

Part of the grouping of mineralogical analyses plotted in Figure 4 probably results from potash feldspar replacing plagioclase. The higher proportion of potash feldspar and corresponding lower proportion of plagioclase in the granitic rocks near Mount Buttle may indicate that replacement of plagioclase by potash feldspar has been more complete in the Mount Buttle area than in granitic rocks from the rest of the Cowichan Lake area. Descriptions of the Saanich granodiorite from the Duncan, Victoria, and Saanich areas given by Clapp (1913, p. 72; Clapp and Cooke, 1917, p. 190) do not refer to potash feldspar poikilitically enclosing other crystals. Poikilitic potash feldspar may be characteristic of apophysal facies of the Saanich granodiorite.

Granodiorite Contacts and Metamorphism.—In describing the metamorphism of wallrocks close to the Saanich granodiorite, three types of contacts have been mentioned: (1) Apparently gradational contacts east of Widow Creek about a mile north of Youbou, (2) complex contact zones in McKay Creek, and (3) simple sharp contacts near the top and on the lower slopes of Mount Buttle. The gradational contact east of Widow Creek has been inferred from serial changes in composition of rocks away from the Saanich granodiorite. At some place in this contact zone more mafic granitic rocks may be in sharp contact with partly granitized volcanics, but such a contact has not been found. Relatively sharp contacts with or without marginal dykes and mainly without a migmatite zone like that at the McKay Creek locality are the commonest type of plutonic contact in the Cowichan Lake area. Except near the top of Mount Buttle, rocks adjacent to the granodiorite have been metamorphosed so that they contain minerals and display textures similar to those of the granodiorite. The granodiorite adjacent to the wallrocks appears to be more mafic than it is farther away, and part of the mafic constituents have probably developed through " basification " of the magma adjacent to mafic wallrocks. The principal difference between the sharp and gradational contacts depends on the extent to which wallrocks have been granitized and the adjacent granodiorite has been " basified."

Contact metamorphism of the volcanic and clastic sedimentary rocks may be described as granitization. Most plutons in the Cowichan Lake area are surrounded by a granitized aureole several tens of feet wide and locally more than a hundred feet wide. Outside the contact aureole and near the granodiorite on Mount Buttle the rocks contain considerable hornblende, smaller amounts of epidote and biotite, and recrystallized plagioclase more sodic than the original. Gross structures are preserved, but the rocks belong to a higher grade of metamorphism than those farther from plutonic masses. In the lower grades of metamorphism, actinolitic hornblende and clinozoisite are characteristic minerals. The development of small amounts of hornblende may have been an isochemical change, but the development of abundant hornblende almost certainly involved the migration of materials. It is uncertain what chemical constituents have migrated, but differences in mineralogy between regionally and contact metamorphosed rocks suggest chemical changes resembling those summarized by Reynolds (1946) as changes leading to granitization.

POST-GRANITIC ROCKS

Post-granitic rocks, including Upper Cretaceous sediments and possible Tertiary intrusive rocks, underlie a relatively small part of the Cowichan Lake area. Sections of the sediments are incomplete and poorly exposed in the Cowichan Lake area, and consequently detailed studies of their lithology were not made during the course of mapping. The sediments are geologically significant, however, in providing evidence from which the post-Cretaceous tectonic history of the region can be deduced.

Nanaimo Group

Conglomerate, sandstone, and shale of the Nanaimo group unconformably overlie the volcanics and the Saanich granodiorite. They occur as discontinuous masses near the bottoms of Chemainus and Cowichan Valleys or as erosional remnants in downfaulted blocks, such as the one between Meade Creek and Youbou Creek or north of Redbed Creek. Only the two lowest formations of the Nanaimo group, the Benson and the Haslam, are exposed in the Cowichan Lake area.

Benson Formation.—The Benson formation is made up of poorly bedded rocks ranging from coarse grey and brown sandstone to boulder conglomerate. The fragments which are subangular to round and are of local origin commonly include cherty tuff, jasper, volcanics of all kinds, and locally granodiorite. Sandy and pebbly conglomerate is generally bedded, but coarser varieties are not.

The conglomerate rests with marked unconformity on older rocks, some of which are fractured and weathered to depths of several feet beneath the unconformity. This depth of weathering is greater than the depth to which weathering has extended from the present surface. Places where the unconformity is exposed are commonly marked by a rusty streak.

The thickness of the conglomerate ranges from nothing, where the Haslam formation rests directly on the crystalline rocks, to a maximum of about 500 feet. Many of the thickest sections of conglomerate are toward the centres of present valleys. South and southeast of Honeymoon Bay, for example, basal arkose of the Haslam formation overlies the volcanics and granodiorite; no conglomerate is present. Two miles west of Honeymoon Bay where the unconformity is exposed, 5 or 6 feet of conglomerate overlies the volcanics. This conglomerate thickens northward toward Cowichan Lake, and on the point northwest of Gordon Bay is at least 500 feet thick. Similar thick sections of conglomerate occur on the west end of the peninsula south of the North Arm of Cowichan Lake. On the north side of the lake the conglomerate thickens from a few feet west of Youbou Creek to several hundred feet in Coonskin Creek, and a similar thickening of the conglomerate occurs in the upper part of Meade Creek. Thickening of the basal conglomerate toward the Cowichan Lake valley suggests that the valley originated as a shallow depression in pre-Upper Cretaceous time.

Haslam Formation.—The Benson formation grades upward into sandstone and shale of the Haslam formation. Lenses of sandstone occur in the upper members of the conglomerate and locally pebble conglomerate is present in the lower part of the Haslam formation. Typically the sandstone of the Haslam formation is brown, poorly bedded, and made up of angular to rounded rock fragments with a calcareous and argillaceous cement. The sandstone is overlain by and grades into black shale that is typical of the Haslam formation. The shale is friable, poorly bedded, and commonly rusty on weathered surfaces. It weathers into ellipsoidal masses with irregular concentric and longitudinal fractures which cause the shale to break into pencil-like fragments. Ellipsoidal and grotesquely shaped siliceous concretions as much as a foot across are common.

The sandstone is generally less than a few tens of feet thick, occurring toward the base of the formation. Black shale, forming the main part of the formation, reaches thicknesses of only a few hundred feet in the Cowichan Lake area but averages 1,500 feet in the Duncan area (Clapp and Cooke, 1917, p. 223) where the section is complete. None of the formations of the Nanaimo group that overlies the Haslam formation in the Duncan area has been recognized in the Cowichan Lake area, and sections of the Haslam formation are incomplete.

Fossils are common in both the shale and sandstone of the Haslam formation. Specimens sent by the writer to the Geological Survey of Canada and identified by J. L. Usher include the following:—

Tellina sp.
Nucula (Acila) truncata, Gabb.
Nucula richardsoni, Whiteaves.
Meretrix (Caryatis) plana, Sowerby.
Dentalium sp.
Anomia vancouverensis, Gabb.
Clisocolus sp.
Inoceramus cf. undulato-plicatus, Roemer.

All were collected along the black shale outcrops in the west fork of Meade Creek and toward the head of Coonskin Creek. Similar fossils were noted elsewhere, and other fossils are particularly abundant in the sandstone near the base of the Haslam formation west of Honeymoon Bay.

Fossils from the Haslam formation collected in the Duncan and Nanaimo areas (*see* Clapp and Cooke, 1917, p. 251) indicate that the formation is Upper Cretaceous. Both the Benson and the Haslam formations have been traced into the Cowichan Lake area along Cowichan Valley and Chemainus River. Isolated masses of these formations can be readily recognized by their distinctive lithologic and stratigraphic characteristics.

Structure.—Rocks of the Nanaimo group have been gently folded along westerly and northwesterly trending axes. The large folds are open, the limbs dipping less than 40 degrees, but small folds are locally close, with dips as high as 70 degrees.

Westerly and northwesterly trending faults displace the Upper Cretaceous sediments. They all dip steeply or are vertical, have a relatively uniform strike, and a tendency to branch. As far as can be determined, most of the movement has been parallel to the dip, but markers are scarce, and it has not been possible to estimate the strike slip on any of the faults. The dip slip of some of the faults can be estimated from the relative position of the Upper Cretaceous sediments and at places from the displacement of members of the Sicker group. However, the displacement cannot be estimated closely because of lack of knowledge of the relief of the post-Cretaceous unconformity and of the amount of folding near the faults. Nevertheless, the following estimates have been made. The south side of the fault along the North Arm of Cowichan Lake appears to have moved downward 1,000 to 1,500 feet in relation to the north, and a similar movement of the order of 2,000 feet has taken place on the fault running west from the west end of the lake. An estimate of the dip slip of the fault extending through Mount Franklin and the head of Cottonwood Creek is more difficult, but judging from the relative positions of the Sicker sediments on both sides of the fault the north side appears to have been downthrown several hundred feet. Limestone of the Sicker group has been displaced between the head of Rift Creek and the top of Mount Spencer in the China Creek area (*see* map, Stevenson, 1944), and a dip slip on the fault in Rift Creek of more than 2,000 feet is indicated.

The unconformity beneath the Nanaimo group at places dips as steeply as 50 degrees and commonly dips 20 to 30 degrees. Relief of the surface on which the sediments were deposited might account for part of the dip of the unconformity, but at places where bedded sediments outcrop close to the unconformity, as in the area west of Honeymoon Bay, the beds above are essentially parallel to the unconformity. Maximum thickening of the Benson formation amounts to about 500 feet in half a mile, indicating a maximum slope of only 10 degrees beneath the conglomerate at the time of deposition, assuming the upper surface of the conglomerate to have been horizontal at that time. Thus it seems probable that tilting of both the Upper Cretaceous and older crystalline rocks must have taken place to cause the unconformity to dip as steeply as 50 degrees. Much of this tilting probably was due to faulting, but gentle folds in the unconformity exposed in Meade Creek east of the North Arm and east and south of Blue Grouse Hill suggest that the older crystalline rocks were folded as well as faulted in the post-Upper Cretaceous orogeny.

Tertiary(?) Intrusive Rock

Small masses of gabbro intrude the rocks of the Sicker group in the Meade Creek area. Four bodies have been mapped, though others too small to map were recognized as probably belonging to this group of intrusive rocks. The rocks are dark green to black, fine to coarse grained, and somewhat resemble intrusive rocks of the Franklin Creek volcanics. These younger gabbros, however, are generally much coarser grained than those of the Franklin Creek volcanics and have no tendency to form sills. In thin sections they are seen to be about one-half labradorite and one-half augite; the latter more or less altered to hornblende.

The contact of one of these masses of gabbro with Saanich granodiorite is exposed on the logging-road in Meade Creek canyon. At this locality the gabbro intrudes the Saanich granodiorite, dykes extending from the gabbro into the granodiorite. The gabbro is finer grained near the contact than at places farther away, and the granodiorite appears altered. Basic dykes cut the Saanich granodiorite elsewhere in the area, but their relation to larger bodies of gabbro is uncertain.

The gabbroic rocks were not found in contact with Upper Cretaceous sediments of the Nanaimo group. Their similarity in form, texture, and composition to Tertiary intrusive rocks of the Sooke district (*see* Clapp and Cooke, 1917, p. 292) 40 to 50 miles south of Cowichan Lake suggests that they may be Tertiary.

CHAPTER III.—MINERAL DEPOSITS

Small shipments of copper and manganese were made from mineral deposits in the Cowichan Lake area during World War I, and copper has been shipped from the Blue Grouse property in recent years. The Cowichan Lake area has been prospected intermittently since about 1900, and mineral deposits containing copper, gold, molybdenum, and manganese have been found. Geologically the deposits fall into four general types, as follows:—

(1) Copper-skarn deposits.
(2) Quartz-sulphide veins near bodies of Saanich granodiorite.
(3) Shear zones in the Franklin Creek volcanics containing sulphides and gold.
(4) Deposits containing manganese minerals, mainly silicates, in the cherty rocks of the Sicker group.

CHALCOPYRITE-SKARN DEPOSITS

Zones of skarn containing chalcopyrite are known at two localities in the Cowichan Lake area—on Blue Grouse Hill* and on the Comego property north of the divide between Widow Creek and Chemainus River. The deposits are similar in mineralogy, and in their relation to the Saanich granodiorite. The mineralized zones contain skarn, a fine- to medium-grained aggregate of brown garnet with minor amounts of epidote, actinolite, quartz, and calcite. Epidote and actinolite are more abundant on Blue Grouse Hill than on the Comego property, whereas quartz and calcite are scarce on Blue Grouse Hill and common at the Comego. Veinlets and disseminated grains of chalcopyrite and pyrrhotite occur in the skarn at both localities, and magnetite is present at the Comego. Sulphides appear to belong to a period of mineralization later than that which formed the skarn.

A small mass of quartz diorite related to the Saanich granodiorite outcrops a few hundred feet from the mineralized zones on the Comego property, and irregular dark- and light-grey feldspar porphyry dykes cut the skarn. Similar dykes elsewhere in the Cowichan Lake area are more numerous near bodies of Saanich granodiorite than far from granodiorite, and therefore are thought to be genetically related to the granodiorite. No granodiorite outcrops near Blue Grouse Hill, but a zone of very irregular feldspar porphyry dykes trends west from Gordon Bay, and it is possible that the skarn mineralization is genetically related to this zone of dykes.

The skarn zones appear to have developed by replacement, but the nature of the replaced material is generally uncertain. On the Comego property, skarn has at places selectively replaced thin-bedded argillaceous or tuffaceous sediments. Lime silicates and calcite in the skarn suggest the original beds were calcareous. On the southeastern end of Blue Grouse Hill, skarn occurs as pods along the edge of a band of limestone. Relatively pure limestone has not been replaced, but the impure beds and volcanic rock along the edge of the band of limestone appear to have been favourable for the formation of skarn. On the top of Blue Grouse Hill the skarn occurs as pods in volcanic rock commonly associated with shear zones. The over-all pattern of the pods of skarn appears to parallel the structure of the volcanic and sedimentary rocks, and hence the primary control of the development of skarn may have been the presence of favourable beds in the volcanic sequence. Chalcopyrite, the chief ore mineral, is confined mainly to zones of skarn, but factors controlling its distribution within these zones are not known.

Blue Grouse

The Blue Grouse property includes three Crown-granted claims—Blue Grouse (Lot 31G), Blue Grouse No. 2 (Lot 32G), and Blue Grouse No. 3 (Lot 33G)—surrounded by about 100 located claims

* A local name used for the hill about a mile west of Gordon Bay.

owned by Cowichan Copper Co. Ltd. The Crown-granted claims are on the top and northeast slope of Blue Grouse Hill, and the main workings are a few hundred feet north of the top of the hill at about 1,400 feet above sea-level. Mineralized outcrops are reported to have been discovered on the property between 1900 and 1910, and some stripping and open-cut work was done before World War I. In 1917, 1918, and 1919 a total of 2,113 tons of ore was shipped. Gross content: Gold, 7 ounces; silver, 1,819 ounces; and copper, 254,587 pounds. In 1918 the main mineralized zones were diamond drilled by The Consolidated Mining and Smelting Company of Canada, Limited. In 1928, Pacific Tidewater Mines Limited drove a short crosscut below the main showing. No further work is reported to have been done until late in 1952, when the property was purchased by Cowichan Copper Co. Ltd., which, on the basis of the 1918 drill records, began mining and exploratory work. The company built a road to Gordon Bay from the public road northwest of Honeymoon Bay, and rebuilt the old road from Gordon Bay to the mine. By the end of September, 1953, an ore-bin had been built and preparations were being made to ship ore. In addition, most of the northeast side of Blue Grouse Hill had been explored by a self-potential geophysical survey under the direction of A. C. Skerl.

The main old working on the property is a big open pit near the top of a steep northeastward-facing bluff a few hundred feet south of the end of the road from Gordon Bay. The pit is about 60 feet long from north to south, 30 to 40 feet wide, and 20 to 40 feet deep. Short branching level workings have been driven westward from the surface to the bottom of the big pit. In the current exploration an old adit, the portal of which is about 280 feet east and 150 feet below the pit, has been extended westward into the hill a distance of about 500 feet. An exploratory raise has been made above the adit about 430 feet from the portal. Other workings on the property include several old open pits, some of which are just north and south of the big pit and others a few hundred feet southwest of it.

The top and northeast slope of Blue Grouse Hill are underlain by basaltic volcanic rocks which are intruded by very irregular bodies of feldspar porphyry. The volcanics include amygdaloids, breccias, pillow lavas, and minor thin-bedded sediments belonging to the upper part of the Franklin Creek volcanics. The origin of the volcanics near the workings is uncertain.

A northerly trending zone of skarn 30 to 40 feet thick and more than 70 feet long is exposed in the big pit. The west side or hangingwall of the skarn is marked by a shear zone that strikes north and dips about 45 degrees westward. In the footwall, skarn grades into relatively unaltered volcanics with no apparent structural break. Irregular masses of feldspar porphyry that intrude the volcanics east and west of the skarn zone are not exposed within it. The skarn is a fine- to medium-grained aggregate mainly of brown garnet. Epidote and actinolite are present locally, especially near the footwall, and disseminated grains and veinlets of chalcopyrite, pyrite, and pyrrhotite occur in some of the skarn. The attitude of the mineralized zone appears to be the same as that of the hangingwall fault, and the old drill records indicate that the fault and the mineralized zone maintain this attitude for as much as 200 feet down the dip. Trenches south along the strike of the skarn zone have slumped, but there is no indication that skarn continues more than a few tens of feet south of the big pit. Outcrops and open-cuts north of the pit show that skarn does not continue more than about 50 feet to the north. An open-cut about 150 feet north of the big pit exposes a small pod of copper-bearing skarn along a shear zone that strikes north and dips about 45 degrees westward, and although this zone is "on strike" and similar in attitude and mineralogy to that in the big pit, mineralization does not appear to be continuous between the pit and the open-cut.

Old records indicate that in 1918 four horizontal holes were drilled westward from the steep hill slope below the big pit. The holes are reported to have intersected the same skarn zone as that exposed in the big pit to depths of about 200 feet down the dip from the bottom of the pit. In the skarn, assays as high as 6.4 per cent copper, and widths of as much as 15 feet, are reported in drill logs to depths of about 100 feet down the dip from the bottom of the pit. Three of the drill-holes intersected the skarn zone directly down the dip from the south end of the big pit. The other, aimed to intersect the skarn zone 30 feet north of the other three, is reported to have intersected "no ore."

Cowichan Copper Co. Ltd., on the basis of these old records, drove a crosscut to follow the lowest diamond-drill hole which had been drilled due west from the face of a short adit. Figure 7 shows a plan and a section of the crosscut, as it was at the end of September, 1953, as well as the approximate position of the big pit. The inner part of the crosscut is in what appears to be a tabular body of feldspar porphyry that dips gently south and strikes east almost parallel to the crosscut. The main skarn zone is not exposed in the crosscut possibly because it is cut out by the feldspar porphyry. The raise above the crosscut, however, intersected skarn and chalcopyrite that probably form the downward extension of the skarn in the big pit. The hangingwall of the mineralized zone in the raise, though not well exposed when seen by the writer, appears to be a fault striking south 10 degrees east and dipping 45 degrees west parallel to the hangingwall fault in the big pit. The footwall is marked by another fault striking south 80 degrees east and dipping 35 degrees south.

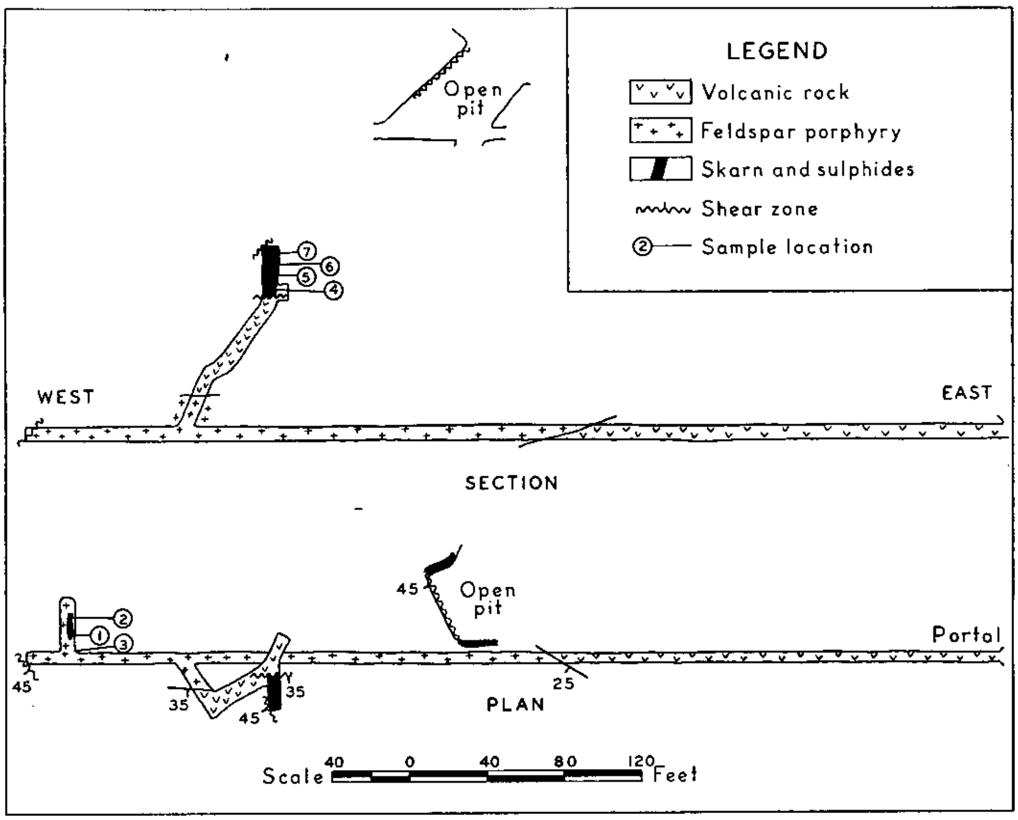

Figure 7. Blue Grouse, section and sketch-plan of crosscut, raise, and open pit.

Skarn in the raise is a massive aggregate of fine- to medium-grained brown garnet with disseminated grains and pods of massive chalcopyrite. A sample selected from one of these pods assayed: Gold, trace; silver, 1.1 oz. per ton; copper, 10.5 per cent. Assays of channel samples taken in the raise are shown in the following table and their locations on Figure 7. Samples 1 and 2 were taken across a lens of skarn exposed in the back of the drift running north from the main crosscut. Sample 3 is from a lens of sheared feldspar porphyry and chalcopyrite about 1 foot long and as much as 4 inches wide.

Sample No.	Width	Gold	Silver	Copper
	Feet	*Oz. per Ton*	*Oz. per Ton*	*Per Cent*
1	2	*Nil*	0.1	0.6
2	5	*Nil*	*Nil*	0.6
3	—	*Nil*	*Nil*	3.5
4	6	*Nil*	Trace	0.6
5	8.5	Trace	0.7	5.0
6	5	0.01	Trace	1.1
7	4.5	*Nil*	0.7	4.7

Ore is reported to have been shipped between 1917 and 1919 from two open-cuts southwest of the big pit. The open-cuts expose two shear zones which strike about south 80 degrees east and dip southward. Skarn, generally containing more epidote and actinolite than that in the big pit and locally containing sulphides, occurs as lenses a few feet wide and a few tens of feet long close to these shear zones.

A geophysical survey, using an electrical self-potential method, is reported to have discovered several areas in which the self-potential is abnormally high. One of these is above the big pit and another is near the open-cut that is 150 feet north of the big pit. A third extends west from the two open-cuts referred to above. A fourth anomaly, reported to cover a larger area than the others, is 600 to 800 feet west of the big pit in an area of little outcrop.

[Reference: *Minister of Mines, B.C.*, Ann. Rept., 1917, p. 267.]

Sunnyside

The property formerly known as Sunnyside is covered by located claims of Cowichan Copper Co. Ltd. It is at the south end of Blue Grouse Hill, less than half a mile south of the Blue Grouse workings. The showings are a few hundred feet above and north of the logging-road that runs west from Honeymoon Bay (*see* Fig. 2).

The property was probably staked prior to 1906 and was actively developed during World War I. A total of 115 tons of ore shipped in 1917 contained 7 ounces of silver and 9,170 pounds of copper. Heavily oxidized dumps, a few open pits and short adits, now inaccessible, comprise the workings.

The deposit is at the eastern end of the Sutton limestone at the point where the limestone appears to pinch out into massive greenstone (*see* p. 24). The greenstone contains no primary structures, and hence is of uncertain origin. Pods of skarn, an aggregate of brown garnet, epidote, and radiating masses of actinolite occur at the contacts of limestone and greenstone. Most of the skarn appears to be near the contacts, but one isolated mass with some limestone occurs in the greenstone north of the main mineralized area, and a few pods of skarn occur in the limestone away from the greenstone. Locally the skarn contains chalcopyrite, but the amount and distribution of the chalcopyrite is erratic. Skarn occurs along the limestone band for about 300 feet, and the best exposed masses of skarn range from a few inches to several feet wide.

[Reference: *Minister of Mines, B.C.*, Ann. Rept., 1917, p. 267.]

Comego

The main mineralized zones on the Comego property are covered by two located claims owned by Duncan Powel, of Duncan. The property is on the east side of the divide between Widow Creek and Chemainus River, about 4 miles north of a point 1 mile east of Youbou. The workings are on the east side of the branch of Chemainus River that flows northeast from Sherk Lake. In the summer of 1951, when the writer visited the property, a private logging-road ran went from Youbou, up Cottonwood and Widow Creeks, to within half a mile of the property, and a trail extended northward from the logging-road past the workings. The showings were originally staked in 1902. It is reported that The Consolidated Mining and Smelting Company of Canada, Limited, did test work and drove a short adit in the 1920's. For several years the property has been worked by A. H. Lomas, of Victoria, and Duncan Powel, of Duncan.

Skarn containing sulphides is exposed in open-cuts and a few short adits along Chemainus River and on the hillside east of the river between elevations of 2,300 and 3,100 feet above sea-level. The mineralized area is underlain by sediments of the Sicker group and sills of diabase belonging to the Franklin Creek volcanics.

The sediments include thin-bedded cherty and argillaceous rocks, massive green sediments, and thin-bedded green sediments partly or completely replaced by skarn. A diabase sill 200 to 300 feet thick outcrops in Chemainus River downstream from and underlying the sediments and the mineralized zones. Discontinuous outcrops of diabase, probably exposures of the same sill, occur east and west of the creek for several hundred feet. Diabase and porphyritic basalt outcrop southeast of the mineralized zones, possibly forming part of a concordant sheet similar to the sill in the creek. The mineralized sediments appear to form a band a few hundred feet thick between these two sheets of diabase.

Dykes of feldspar porphyry intrude the sediments and are exposed both in the mineralized zone and in Chemainus River north of it. The dykes are not mineralized, but it is not known whether they are earlier or later than the mineralization. In general in the Cowichan Lake area such dykes are close to bodies of the Saanich granodiorite and are thought to be genetically related to them. Quartz diorite outcrops in a few places on the crest of the ridge about 250 feet south of the workings.

Because of the scarcity of outcrops on the Comego property, little is known of the structure of the underlying rocks. Most of the sediments exposed in the workings and in Chemainus River north of the workings strike about northwest and dip 20 to 40 degrees southwest. In Chemainus River, south of the workings, cherty tuffs with about the same strike dip 40 degrees northeast. Mineralized sediments in a short adit about 1,500 feet east of Chemainus River strike north 30 degrees east and dip 30 degrees northwest. Rocks of the same series in surrounding areas lie in a system of northwesterly trending folds. Knowledge of this structural trend, together with the above observations, suggests that the sediments and the diabase on the Comego group may form an open northwesterly trending syncline, possibly complicated by minor cross-folds.

Three types of mineralization occur on the property. The most widespread type is skarn, a medium-grained aggregate of brown garnet, actinolite, quartz, and calcite, which at many places contains magnetite and sulphides, mainly chalcopyrite, pyrite, and pyrrhotite. The second consists of rusty-weathering quartz-carbonate veins and replacements, and the third of quartz-molybdenite veins.

Chalcopyrite and skarn are exposed in the banks of Chemainus River at a point where the trail to the Silver Leaf mine crosses the river. Bedrock is covered by overburden away from the river, but an open-cut in the east bank has exposed two lenses of massive chalcopyrite about 2 feet wide and 4 feet long. The surrounding skarn exposed over an area about 6 feet wide and 10 feet long contains disseminated chalcopyrite. Long axes of the lenses of massive sulphides trend westward. In Chemainus River, along strike from these lenses and as far as the limit of outcrop on the west bank of the river 30 to 40 feet from the massive lenses, outcrops are calcareous material containing small amounts of disseminated pyrite, chalcopyrite, and grey copper. The mineralized zone is cut off on the north by a thick sill of diabase, and to the south the rusty calcareous material contains no chalcopyrite. This mineralized zone at the point where the Silver Leaf trail crosses Chemainus River will be referred to as "A" zone, and the other showings on the property are described in relation to it.

About 700 feet south of the "A" zone, disseminated chalcopyrite in a quartz-rich skarn is exposed in a trench on the east bank of Chemainus River. This skarn locally contains molybdenite, but the distribution of the sulphides is erratic, and the mineralized zone has not been traced beyond the limited exposures in the river. About 1,200 feet south, and 600 feet east of "A" zone, as well as about half a mile southeast of "A" zone, open-cuts and a few short adits have been made in zones of skarn containing sulphides and magnetite. Pyrrhotite is the main sulphide in these zones, although pyrite and chalcopyrite are present locally.

The main skarn zone on the property is exposed on the hillside east of Chemainus River. It is 30 to 40 feet wide and extends 300 to 400 feet southeast from the " Molybdenite tunnel," a short adit 420 feet south and 1,420 feet east of "A" zone. In the " Molybdenite tunnel " and in an open-cut near the east end of the zone, beds of skarn grade into and alternate with beds of green sediments in a way that suggests the skarn has replaced favourable beds in the sediments. Poor exposures and scarcity of outcrops away from old trenches that expose the zone make the extent and attitude of the skarn mineralization uncertain. Rocks favourable for mineralization probably occur beneath the overburden beyond the limits of the zone now exposed, and pieces of skarn found in the overburden at several widely separated places mainly southeast of the mineralized zone suggest that skarn may be more widespread than the outcrops indicate. Chalcopyrite occurring as lenses and disseminated grains is common in the skarn now exposed, and appears to be mainly confined to it, but factors controlling the distribution of chalcopyrite in the skarn are not known.

The following table gives assays of ten samples of the highest-grade copper-skarn mineralization seen on the property. Samples 1 to 8 were taken by W. J. Lynott, who visited the property for the British Columbia Department of Mines in September, 1946; samples 9 and 10 were taken by the writer in 1948. The location of the samples is recorded in the table as distances south and east of "A" zone. Where structures are visible, widths of the samples were measured at right angles to structures in the mineralized zone.

Sample No.	Location in Relation to "A" Zone	Width	Gold	Silver	Copper
		Inches	Oz.	Oz.	Per Cent
1[1]	At "A" zone	26	0.26	0.1	9.8
2	At "A" zone	24	0.26	0.4	6.8
3	At "A" zone	48	0.02	0.2	2.3
4	680 feet due south, east bank of Chemainus River	72	*Nil*	0.1	1.8
5	680 feet due south, east bank of Chemainus River	60	*Nil*	*Nil*	0.2
6[2]	420 feet south, 1,420 feet east at adit portal	15	0.02	0.8	2.7
7[1]	750 feet south, 1,800 feet east in trench	120	0.06	0.8	3.0
8	1,050 feet south, 2,400 feet east	96	*Nil*	0.4	2.5
9	720 feet south, 1,750 feet east	72	0.02	0.5	1.8
10	720 feet south, 1,750 feet east adjacent to 9	48	0.04	0.8	2.2

[1] Assayed a fraction of 1 per cent tungsten.
[2] *Assayed 1.3 per cent molybdenum.*

The second type of mineralization on the Comego property, exposed only in Chemainus River south of "A" zone, consists of rusty-weathering quartz-carbonate veins and replacements. The vein material is conspicuous because it weathers an orange-brown owing to the presence of iron-bearing carbonates and pyrite. It occurs as tabular or lens-shaped bodies 75 feet or more long and as much as 3 feet wide along steeply dipping shear zones. At two places for distances of more than 200 feet along Chemainus River the outcrops are entirely of rusty vein material, and the attitude and extent of these masses is obscure. Similar veins are common at other places in the Cowichan Lake area, but none is known that contains ore minerals.

The third type of mineralization consists of quartz-molybdenite veins and replacements. Molybdenite is widely distributed in minor amounts throughout the mineralized area, occurring as flakes as much as one-eighth of an inch across in quartz veins, or less commonly disseminated in skarn. Skarn containing molybdenite appears to be high in quartz, and assays show tungsten to be present locally. The quartz veins contain medium-grained white and rusty quartz, disseminated molybdenite, pyrite, and chalcopyrite. The largest seen by the writer, about a foot wide, is exposed near the portal of the " Molybdenite tunnel." The veins resemble those of the Allies molybdenite property on Mount Buttle (*see* p. 60).

[References: *Minister of Mines, B.C.,* Ann. Rept., Cascade property, 1906, p. 211; Kitchener property, 1919, p. 239; 1948, p. 160. Clapp, C. H., *Geol. Surv., Canada,* Mem. 13, pp. 164–170.]

QUARTZ-SULPHIDE VEINS

Sulphide-bearing quartz veins near bodies of Saanich granodiorite have been recognized at several localities. The principal occurrence of these veins is on Mount Buttle, where the main sulphide is molybdenite. Similar veins containing pyrite, chalcopyrite, with or without molybdenite have been found on the Comego property (*see* p. 59) and on the Brass claim in Jump Creek.

Allies

A considerable amount of work has been done on the Allies group of claims, but the ground has not been staked for several years. The property is on the ridge and northeast slope of the ridge north of Mount Buttle. The showings are between elevations of about 2,700 and 4,200 feet above sea-level. In 1951 they could be reached from Cowichan Lake by climbing the steep southeast slope of Mount Buttle from the logging-road in McKay Creek, or from Nanaimo River by hiking south through thick undergrowth from the small lake at the end of the trail up Green Creek, a distance of about a mile. The original mine trail from the head of Jump Creek around Delphi Lake in 1951 was almost obliterated by undergrowth and fallen trees, and the cabin, at an elevation of 3,000 feet on the northeast slope of the ridge north of Mount Buttle, was beginning to fall down. The first recorded work on the property was done toward the end of World War I, and although the writer could find no record of work since then, it is probable that some work was done in the ten-year period before 1939. The five or six claims comprising the property were held by record by Archie Cowie and associates, of Nanaimo.

The quartz veins occur in granitic rocks, mainly granite and granodiorite, near the upper and western contact of a body of the Saanich granodiorite with greenstone of the Sicker group. The veins in general strike slightly west of north and dip steeply east, although some differ markedly from this attitude, and the narrowest veins are irregular. They contain medium to coarsely crystalline quartz locally exhibiting comb structure and small vugs. Sulphides including chalcopyrite, pyrite, and molybdenite are erratically distributed through the veins, molybdenite commonly occuring in rosettes, and the other sulphides as coarse crystals and aggregates.

Twenty-three workings, mainly open-cuts but including a short adit and an inclined shaft, are described in British Columbia Department of Mines Bulletin No. 9, 1940, by J. S. Stevenson, who states: "The veins range in width from 1 inch to 54 inches, and in exposed length, from a few feet to an observed maximum of 37 feet. They occur over an area that measures 6,500 feet in a north-south direction, by 1,800 feet in an east-west direction. Samples taken by the writer from mineralized quartz veins assayed: Molybdenite, trace to 0.4 per cent."

[References: *Minister of Mines, B.C.,* Ann. Rept. 1908, p. 150; 1930, p. 302. Stevenson, J. S. (1940), *B.C. Dept. of Mines,* Bull. 9, 1940, pp. 73–76.]

Delphi

The Nanaimo Copper Syndicate Ltd., of Nanaimo, owns three Crown-granted claims near the head of Jump Creek. The claims are the Brass (Lot 78), Iron Crown (Lot 79), and Tyro (Lot 77), and are collectively called the Delphi group. The claims were staked about 1900, and the first work is recorded as having been done in 1902. By 1908 apparently all the workings that exist to-day, including an 80-foot shaft on the Brass claim, a 30-foot shaft on the Iron Crown, and a short adit on the Tyro claim, had been completed.

The workings are between elevations of 2,500 and 3,000 feet above sea-level west of the main branch of Jump Creek. This branch flows south from the pass between Bell and Jump Creeks. The workings may be reached from the small lake at the end of the Green Creek trail by following an old trail in the general direction of north 60 degrees east a distance of half a mile.

The shaft on the Brass claim is 30 to 40 feet west of Jump Creek at an elevation of about 2,550 feet. Rocks exposed in the creek are porphyritic volcanics of the Sicker group. They are cut by two discontinuous quartz veins striking north 5 degrees east and dipping steeply eastward. The veins are 40 to 50 feet long and less than 8 inches wide, and both contain white quartz with masses of pyrite as much as 3 inches in diameter. A sample taken across one vein at a point where it contained considerable pyrite assayed: Gold, *nil;* silver, *nil;* copper, trace. Pieces of quartz and calcite containing pyrite and minor amounts of chalcopyrite make up a small proportion of the rock on the dump, and suggest that a vein similar to those in the creek was cut in the shaft.

The shaft on the Iron Crown claim is about 900 feet in a direction of north 75 degrees west from the shaft on the Brass claim. It has been sunk on an outcrop of volcanic rock containing disseminated pyrrhotite, pyrite, and minor chalcopyrite. The extent and attitude of this mineralized zone is unknown because outcrops are scarce and the mineralized rock is massive.

The adit on the Tyro claim is at an elevation of 2,900 feet, about 1,300 feet north 20 degrees west of the shaft on the Iron Crown claim. The adit has been driven north 20 degrees east about 45 feet in altered green volcanic rock which locally contains lenses and veinlets of white quartz. The lenses are a few inches wide, strike north and dip steeply. No sulphides were seen in them.

[References: *Minister of Mines, B.C.,* Ann. Rept., 1908, p. 150; 1930, p. 302.]

SHEAR ZONES IN THE FRANKLIN CREEK VOLCANICS

The Franklin Creek volcanics on Mount Landalt, El Capitan, and Mount Service are cut by easterly striking, steeply dipping shear zones which contain sulphides and gold. A few of the shear zones are as much as a mile long and are exposed over a vertical distance of 2,000 feet, but none of these is known to be mineralized. Shorter zones are much more common and at places contain pyrite, pyrrhotite, chalcopyrite, arsenopyrite, as well as small amounts of quartz and calcite. Gold is reported to have been seen in one of these zones, and assays as high as 1 ounce per ton have been obtained from samples from a few of them. Rusty zones, or those containing most sulphides, usually contain most gold. A small amount of exploratory work at several places and considerable work on the El Capitan and Silver Leaf showings have been done at intervals over a period of years, but no ore has been shipped.

El Capitan

The El Capitan group includes claims that since 1933 were held by record by D. Powel and G. Lomas, of Duncan. In 1954 the ground was not staked. The claims are about 5 miles due north of Youbou and are reached by logging-road and trail from Youbou. The logging-road crosses the Canadian National Railway 1 mile west of Youbou and follows the west bank of Cottonwood Creek for 1 mile. A trail continues up Cottonwood Creek about 5 miles to Lomas Lake. Workings on the El Capitan claims are about 2,000 feet east of the lake on both sides of a mountainous divide between Cottonwood Creek and Chemainus River. They include two short adits, No. 1 and No. 2, at elevations of 4,550 and 4,490 feet above sea-level on the east side of the divide, and one adit, No. 3, at 4,350 feet on the west side of the divide (*see* Fig. 8). Hillsides and summits near the workings are steep and rocky, and the more gentle slopes are covered by heather and thick clumps of alpine trees.

The first El Capitan claim was staked in 1925, and most work was done between 1927 and 1933. The original discovery was on the east side of the divide, and adits No. 1 and No. 2 were driven in 1927 and 1928 to explore it. In 1932 and 1933 No. 3 adit was driven on the west side of the divide in the hope of encountering the same mineralized zone as that discovered above on the east side.

The claims lie within an area of flat-lying flows and sills of Franklin Creek basalt. Near the workings the rocks are massive porphyritic basalt containing phenocrysts of white-weathering plagioclase feldspar as much as 3 millimetres across in a dense dark-green to black groundmass. The adits have been driven to explore an easterly striking,

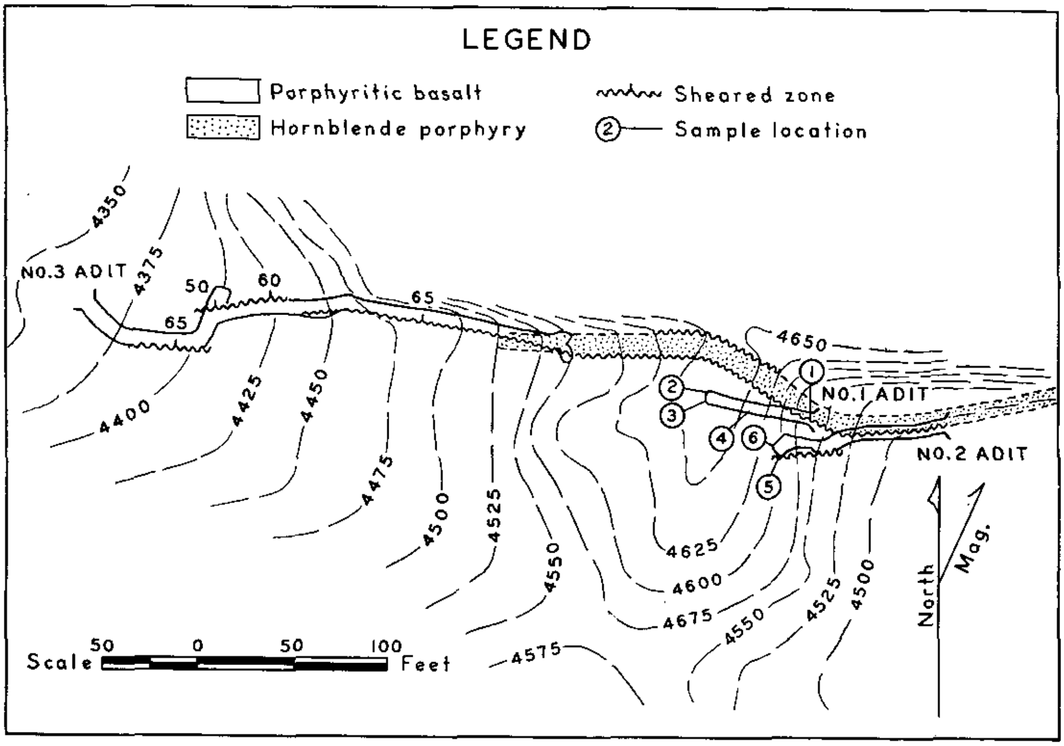

Figure 8. El Capitan—composite plan of workings and geology.

steeply dipping shear zone which cuts the basalt and contains sheared rock and oxidation products of iron and copper. The main shear zone follows the south wall of a hornblende porphyry dyke containing dark hornblende phenocrysts as much as 3 millimetres long in a light-coloured, very fine-grained groundmass. The dyke, which averages 10 feet wide, strikes about north 80 degrees west, dips steeply southward on the east side of the divide, but on the west side of the divide dips vertically and steeply northward. The shear zone can be traced on both sides of the sharp-crested divide for a distance equivalent to about 200 feet horizontally and about 200 feet vertically. The sheared and oxidized material is nowhere more than 4 feet wide, but in places shearing shows on both sides of the dyke. Below No. 2 portal on the east slope of the divide, no oxidized material can be seen in the shear zone, and a short distance east little or no shearing can be seen on either side of the dyke. On the west side of the divide the dyke and shear zone are exposed to within a short distance of No. 3 adit, but below the adit, and for a short distance above it, they are drift-covered. Samples, the assays of which are shown in the following table, were taken in what appeared to be the highest grade material in the shear zones. In addition to gold and silver, all contain traces of copper.

Sample No.	Adit	Width	Gold	Silver
		Inches	Oz.	Oz.
1[1]	No. 1	30	0.18	Trace
2	No. 1	8	0.01	Trace
3	No. 1	6	0.36	0.1
4	No. 1	24	0.42	0.3
5	No. 2	9	0.01	0.1
6	No. 2	10	0.92	0.6

[1] Contains 0.6 per cent copper.

The location of the samples is shown on Figure 8.. In No. 1 adit the shear zone containing sheared basalt and rusty oxidized material is 2½ feet wide at the portal, 4 feet wide 25 feet from the portal, and branches to two zones 6 to 8 inches wide near the face. No. 2 adit follows the same shear zone for about 90 feet, and in it the zone varies in attitude and width, and the oxide-bearing zones are discontinuous. No. 3 adit was driven in the hope of finding the shear zone exposed in No. 1 and No. 2 adits. The hornblende porphyry dyke and shear zone are not exposed in No. 3 adit but are reported to have been found about 20 feet north of the adit in two crosscuts now filled with waste rock. The adit follows a continuous shear zone, parallel to the main shear zone and containing sheared basalt but no rusty oxidized material. A little copper stain shows on the wall of the adit about 20 feet from the portal, and a small chalcopyrite-bearing quartz stringer is exposed in the face.

[References: *Minister of Mines, B.C.,* Ann. Rept., 1927, p. 337; 1928, p. 364; 1932, p. 202; 1935, p. 52.]

Cottonwood Workings on the claim, referred to in old reports as the Cottonwood, are between elevations of 3,850 and 4,000 feet above sea-level about 1,500 feet northwest of Lomas Lake. In recent years the claim has been relocated under several different names, and in 1954 the ground was open.

The workings expose a more or less continuous shear zone in the porphyritic basalt that strikes about north 70 degrees east and dips steeply northward. The upper adit, at an elevation of 3,975 feet, has been driven in the general direction of north 80 degrees east a distance of 60 feet along the shear zone. Sheared basalt containing porous iron oxides and a few lenses of quartz is exposed throughout the length of the adit, and two irregular quartz veinlets about 6 inches wide occur in the face. A sample taken across 2.5 feet in the face contained no gold or silver, and one taken about 20 feet from the face, across 2 feet, made up of heavily oxidized material assayed: Gold, 0.12 oz. per ton; silver, 0.60 oz. per ton.

Two open-cuts and two short adits have been made in the hillside below the upper adit and expose several minor faults containing 6 to 8 inches of sheared basalt and local concentrations of iron oxides. In the lower of the two cuts some pyrite and pyrrhotite are disseminated through the basalt. The lowest adit, at an elevation of 3,850 feet and about 200 feet south 80 degrees west of the portal of the upper adit, is about 50 feet long and follows what is probably the same shear zone as that in the adits and open-cuts above. Sheared basalt is exposed in the adit, and material on the waste dump, reported to have been taken from a small lens of sulphides near the portal, contains massive sulphides. These include pyrite, pyrrhotite, arsenopyrite, chalcopyrite, and probably cobalt sulphides as some samples are coated with erythrite. Two specimens were tested with a Geiger counter but no radioactivity could be detected.

[Reference: *Minister of Mines, B.C.,* Ann. Rept., 1927, p. 338.]

Silver Leaf The Silver Leaf group consists of two Crown-granted claims, the Mountain Ash (Lot 28G) and Silver Leaf (Lot 29G), and the Hemlock Fraction (Lot 30G), owned by R. G. Gore-Langton and associates, of Duncan. The Mountain Ash claim was staked in 1911, and the others shortly after by the late Thomas Service, of Lake Cowichan. The workings are between elevations of 2,400 and 2,600 feet above sea-level on the west side of a creek flowing northward from the pass west of El Capitan into a tributary of Jump Creek. A trail, originally used for pack-horses, extends from the logging-road near the head of Widow Creek to a cabin at an elevation of 2,200 feet on the creek east of the Silver Leaf workings. The workings include three adits driven westward at the base of a bluffy hillside to follow two shear zones (*see* Fig. 9). No. 1 adit was driven before 1923, and the other two are reported to have been driven during the summer of 1945.

The shear zones cut massive Franklin Creek basalt. The most southerly zone, exposed in Nos. 1 and 2 adits and on the surface above the adits, strikes westward and

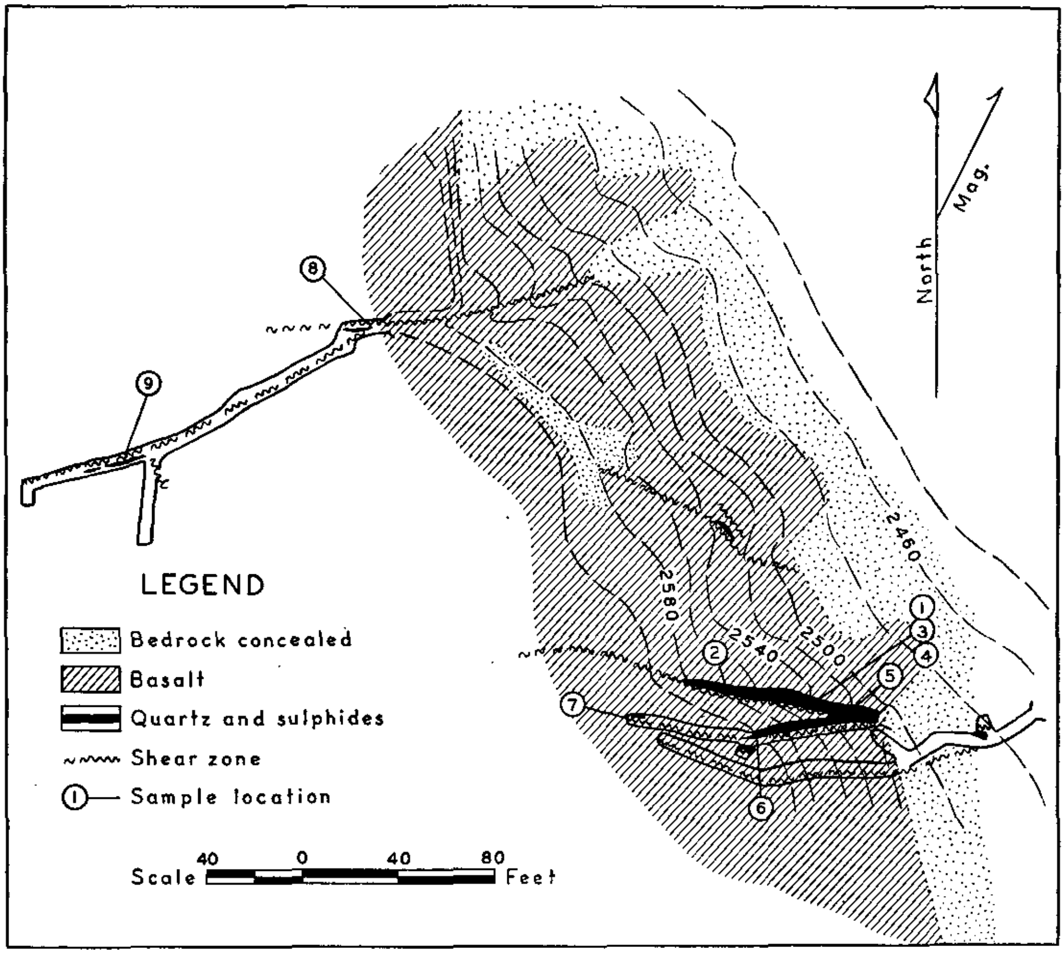

Figure 9. Silver Leaf—composite plan of workings and geology.

dips 65 degrees to the south. On the surface a lens of oxidized sulphides in the shear zone is exposed at the portal of No. 1 adit and extends westward up the steep slope above the portal a horizontal distance of 95 feet. The sulphide zone is 4 feet wide at the portal and maintains this width for about 50 feet but tapers to nothing to the west. The shear zone continues for several hundred feet up the hill, but very little sulphide was seen west of the main showing. The sulphide zone occurs in No. 1 adit extending from the portal to a shallow winze about 60 feet from the portal. Talus covers the hillside below No. 1 adit, and in No. 2 adit lagging covers the walls near the portal, but sulphides are exposed in the back of No. 2 adit a distance of about 20 feet from the portal. No. 2 adit follows the shear zone to the face, about 150 feet from the portal, but very little sulphide was seen in it beyond about 30 feet from the portal. Thus the sulphide zone in general appears to form a lens, thinning to the west and downward.

The mineralized parts of the shear zone contain massive fine-grained sulphides including pyrite, chalcopyrite, pyrrhotite, and minor arsenopyrite. Quartz, calcite, and sheared basalt make up the gangue. Lenses of greenstone low in sulphides are present in some parts of the sulphide zone. Assays in the following table give values in copper, gold, and silver and spectrochemical analyses indicate that no other metals are present in significant amounts.

Sample No.	Width	Gold	Silver	Copper
	Feet	Oz.	Oz.	Per Cent
1[1]	2.7	0.24	0.6	—
2	3.5	1.14	2.8	12.9
3	1.2	0.68	1.9	15.3
4	2.0	0.52	1.7	14.5
5	4.0	0.10	0.2	2.3
6	4.5	0.50	4.4	4.5
7[1]	1.5	*Nil*	Trace	—
8	1.0	0.18	0.2	3.1
9[1]	1.0	1.22	0.2	—

[1] Contains no visible chalcopyrite.

No. 3 adit, about 250 feet northwest of No. 1, follows first a westerly trending shear zone for about 20 feet, then follows a zone trending south 60 degrees west a distance of 150 feet to the face. The westerly trending zone dips steeply southward and the other zone is vertical. Sulphides including pyrite, chalcopyrite, and arsenopyrite occur locally across widths of as much as 1½ feet. Two assays of samples (Nos. 8 and 9) taken in No. 3 adit are given in the table above (*see* Fig. 9).

The rock chimney above No. 3 portal exposes a shear zone, probably the same one as that trending south 60 degrees west in the adit. The zone ranges from 3 to 4 feet wide and contains lenses of sulphides as much as 6 inches wide. A sample of this material about 120 feet from No. 3 portal across a 4-foot width assayed: Copper, 7.2 per cent, and traces of silver and gold. Another taken about 250 feet up the chimney from the portal across a 3-foot width assayed: Copper, 2.5 per cent; gold, 0.24 oz. per ton; silver, trace.

A mineralized zone on the Mountain Ash claim is reported to occur at an elevation of 3,100 feet, about 1,000 feet south of No. 1 adit.

[References: *Minister of Mines, B.C.,* Ann. Rept., *1923,* p. 243; *1927,* p. 348; 1928, p. 376.]

MANGANESE DEPOSITS

Manganese minerals occur at several places in the cherty members of the Sicker group north of Cowichan Lake. The most westerly occurrence, known as the Black Prince, is near the head of Shaw Creek; the most easterly, the Hill 60, is about 4 miles east of Lake Cowichan. Between these, in a belt about 4 miles wide, along the north side of Cowichan Lake, six other occurrences are known.

The Hill 60 deposit was first staked in 1918, and in 1919 and 1920 is reported to have shipped 1,117 tons of ore. This production stimulated prospecting, and by 1920 several other occurrences including the Black Prince and the Cottonwood deposit on Widow Creek had been found. No ore was shipped from Hill 60 after 1920, and little interest was taken in any of the deposits until about 1939. In 1939 trainees of the Dominion-Provincial Mining Training Project cleaned out and extended trenches on the known occurrences and found several others, which they explored by trenching and stripping. In 1954 none of the deposits was staked. Most of these occurrences are shown on the map (*see* Fig. 2), though the Hill 60 and one or two small occurrences west of Hill 60 are east of the east edge of the map. The writer visited most of the occurrences in 1948.

The manganese deposits occur in cherty members of the Sicker group, principally within the lower part of the 600 feet of cherty tuff immediately above the marker described on page 18. The manganese deposits are associated with massive brick-red jasper occurring in beds 6 inches to 3 feet thick, or with red, pink, and white cherty sediments interbedded with less brightly coloured cherty tuffs. These red sediments, rich in hematite, are present at all the manganese deposits seen by the writer but also occur locally in the cherty members of the Sicker group, where no manganese deposits are known. Under the microscope, cherty rocks in which manganese occurs appear to be coarser grained and richer in quartz than the normal cherty tuffs. The quartz has a mosaic texture in thin sections, occurring in grains as much as 0.2 millimetre across. Outlines of radiolaria(?) (*see* p. 15) are present in some sections, but are less distinct than those in cherty tuffs away from the manganese deposits.

The primary manganese minerals, which are mainly silicates, occur in roughly lenticular masses with long axes parallel to the bedding of the enclosing sediments. The lenses range from a fraction of an inch (*see* Plate XIV) to several feet thick, and from a few inches to as much as 40 feet long. Little is known of the dimension of mineralized zones down the dip, but it probably differs little from that parallel to the strike. Larger lenses are shorter in relation to their thickness than smaller lenses and appear to be made up of a number of small lenses. Tight folding of the beds and of the manganiferous lenses has modified the lenticular character, and oxides on the surface at several places obscure the form of the deposits.

Manganese oxides coat the outcrops at all the occurrences, but fresh silicates commonly occur a few inches beneath the surface. At several localities a good proportion of the silicates are oxidized to a depth of several feet, and at the Hill 60 deposit oxidized material is reported to have extended to a depth of 15 feet.

The chief primary manganese mineral is rhodonite, which is characteristically pink but locally is brick-red. Rhodonite occurs as lenses parallel to the bedding of the sediments, as veinlets cutting across the bedding, or as fine- to medium-grained irregular masses. Texturally it appears to replace the cherty sediments. Lenses parallel to the bedding have scalloped edges and terminate with blunt irregular ends, veinlets commonly merge with rhodonite-bearing bands parallel to the bedding, and the irregular masses display no primary structures.

Garnet was found in several thin sections of the manganese-bearing rocks but is too fine grained to be recognized in hand specimens. Brown bands associated with manganese-bearing rocks, however, commonly contain garnets. As seen in thin section, they appear as euhedral crystals, about 0.1 millimetre across, occurring in bands parallel to the bedding of the sediments. The garnets are probably manganiferous, though their exact identity is uncertain.

A yellow manganese-bearing chert is common at the Hill 60 deposit and occurs in small amounts at several of the other deposits. This material, by itself, associated with rhodonite, or cut by fractures containing black oxides, is used locally by lapidaries, but the identity of the yellow constituent has not been determined. X-ray, spectrochemical, and optical studies indicate that the yellow mineral is a type of manganese garnet.* In hand specimens it appears to form very closely spaced, fine irregular bands in the chert. In thin sections the bands are seen to be composed of equidimensional grains of high relief but too small for identification.

Rhodochrosite is present in small amounts in some of the deposits, especially at the Cottonwood near the head of Widow Creek. At this locality it occurs as a brown massive rock which in thin section appears to be about one-half rhodochrosite and one-half rhodonite. The rhodocrosite seen in thin section occurs as irregular masses that grade into finely crystalline rhodonite, giving a texture that suggests the rhodochrosite has replaced the rhodonite.

The disseminated grains of pyrite occur with the manganese minerals at Hill 60 and are present at several of the other occurrences. Quartz veinlets are common, and at Hill 60 contain pyrite and chalcopyrite.

The manganese deposits are fundamentally of two possible origins; either they are epigenetic replacement deposits or metamorphosed sedimentary deposits. Individual outcrops and hand specimens show that the manganese silicates have replaced the sur-

* Spectrochemical analyses of small chips of the yellow chert show that in addition to manganese and silica, aluminium, calcium, and iron are the essential constituents. X-ray powder photographs of similar yellow chert taken by R. M. Thompson, of the University of British Columbia, give patterns, when due allowance has been made for the extra quartz lines, very similar to those for spessartite, the manganese garnet. Dr. Thompson concludes that the mineral is " not pure spessartite but possibly something between spessartite and grossularite."

rounding chert at least on a small scale. General features of the deposits and their similarity to others known to be of sedimentary origin, however, have led the writer to believe that they are probably metamorphosed sedimentary deposits.

Small-scale textural and structural features, such as lenses of rhodonite with blunt, feathered ends that grade into thinly banded chert, or veinlets of rhodonite that spread out along bedding planes, are characteristic of replacement. The mosaic texture and relatively coarse grain size of the cherts near manganese deposits indicate that they have been affected by replacement and recrystallization. The lens-like shape and restricted stratigraphic range of the deposits may equally well be features of sedimentary deposits or features of selective replacement, but when it is considered that the cherty tuffs are probably syngenetic or diagenetic (*see* p. 15), it seems unlikely that widespread replacement should have taken place selectively in cherty rocks that appear to be no more favourable for replacement than any others in the Sicker group. The association of manganese with bedded chert, and with volcanic rocks, has been described from several localities throughout the world and suggests that manganese, chert, and volcanics are related in origin. Metamorphism of manganiferous sediments typically produces manganese garnet and rhodonite. In the cherty tuffs of the Sicker group, veinlets of quartz and plagioclase formed by solution and reprecipitation of materials in surrounding rocks are common. The textural and structural features of replacement exhibited by the manganese deposits may similarly have formed by redistribution of manganese of sedimentary origin.

Manganese ore shipped from the Hill 60 deposit is reported to have averaged more than 50 per cent manganese and less than 20 per cent silica. Analyses of samples from Hill 60 reported in the British Columbia Minister of Mines Annual Reports for 1918, 1919, and 1920 range from about 16 to 55 per cent manganese and from 6 to 60 per cent silica. About the same grade is reported from the Black Prince. Many of the samples as well as the ore shipped are relatively low in silica, and hence were probably taken from oxides near the surface. Picked samples of silicates from below the zone rich in oxides range from about 14 to 30 per cent manganese and are high in silica.

Under present conditions the only economic grades are of oxidized material, unless the primary minerals can be mechanically concentrated. Residual deposits of oxides that may have accumulated in pre-glacial times have probably been destroyed by glacial erosion. Under favourable circumstances, however, such as beneath Upper Cretaceous sediments, residual deposits may exist, though none of the Upper Cretaceous sediments in the Cowichan Lake area appear to cover especially favourable rocks. Attempts to find bog manganese and transported oxides in valleys and depressions below primary silicate deposits have been unsuccessful.

Hill 60

The Hill 60 manganese deposit is 4 miles east of the village of Lake Cowichan. The main workings are at an elevation of about 2,600 feet above sea-level near the top of the steep north slope of Cowichan Valley. The deposit was discovered in 1918, and in 1919, 530 tons of ore averaging 50 per cent manganese and 19 per cent silica is reported to have been shipped. In 1920, 587 tons of ore was shipped, but since then no work, other than prospecting and cleaning out of old workings by trainees of the Dominion-Provincial Mining Training Project, has been recorded. Consequently, the wagon-road from Cowichan Valley to the mine over which the first ore shipments were taken is badly grown over, and only one or two towers of the aerial tramway running south from the workings over which the last ore was shipped remain standing. In 1951 the best way to reach the property was to leave the Duncan–Lake Cowichan Highway about 4 miles from Lake Cowichan and to climb the bluffs north of the highway.

The north side of Cowichan Valley near the Hill 60 deposit is underlain by cherty tuffs of the Sicker group that strike north 65 to 70 degrees west and dip southwestward at angles greater than 55 degrees. The cherty tuffs are intruded by relatively large masses of gabbro, possibly part of the Franklin Creek volcanics. Rocks associated with the manganese occurrences are thinly banded, green, cream, and red cherty tuffs locally containing lenses of massive red jasper. These rocks are cut by a few thin basic dykes near the main Hill 60 workings.

Ore was shipped from an open pit about 60 feet long in a northwesterly direction, 20 to 30 feet wide and 15 to 20 feet deep. An adit, now caved but reported to be connected to the bottom of the pit by a shaft 10 to 20 feet deep, has been driven from a point a few tens of feet southwest down the hill from the pit. Small open-cuts have been made close to the pit, and others have been made several hundred feet northwest and east of it.

The grade of the ore shipped indicates that it was largely oxidized, and although most of the walls of the main pit and the manganese-bearing outcrops are coated with black oxides, these are rarely more than a few inches thick. Pink rhodonite with small amounts of yellow manganiferous chert occur in the northeast corner of the pit, brick-red rhodonite occurs along the southwest side, and red cherty tuff with minor manganese silicates and a coating of oxides occur at the northwest end. The bottom of the pit is covered by broken rock, mainly manganese silicates coated with oxides. In mining, oxides are reported to have given way to silicates at a depth of about 15 feet, and no silicates and very little oxide is reported to occur in the adit beneath the pit.

Thin lenses of manganese silicate are present in the cherty tuffs more or less along strike from the occurrences in the main pit but not continuous with them. One such lens is exposed in outcrops and small open-cuts about 600 feet east of the pit. There, manganese silicates coated with oxide occur as discontinuous lenses parallel to the bedding of steeply dipping cherty tuff and cover an area about 70 feet long and a few feet wide. Similar lenses occur in the cherty tuffs several hundred feet northwest of the main pit, as well as along the eastern wall of a steep canyon the head of which is about 500 feet west of the pit.

Other Manganese Deposits

Two or three small occurrences of manganese minerals in cherty tuff are reported to have been found between the main Hill 60 showings and the eastern edge of the Cowichan Lake map-area, but none of these was seen by the writer. Within the Cowichan Lake area, occurrences of manganese are known near Stanley Creek, east of Meade Creek, near Widow and Wardroper Creeks, and west of Shaw Creek (*see* Fig 2). Although these include all the significant occurrences known to the writer, others are certainly present in the cherty tuffs of the Sicker group, since blocks of manganese-bearing chert in the float have been seen at a number of places far from known outcrops of manganese minerals but near outcrops of cherty tuff similar to that in which manganese commonly occurs. The known deposits and most of this type of float are near Cowichan Lake, but a few pieces of float and favourable-looking cherty tuff were seen east of Rheinhart Lake and on both sides of Green Creek north of Bell Creek.

The occurrence east of Stanley Creek is reported to consist of two irregular lenticular masses of manganese silicate parallel to the bedding of cherty tuff, a few inches to a foot wide and about 20 feet long.

The occurrence about a mile east of Meade Creek is exposed in two shallow open-cuts about 200 feet apart. Lenses containing rhodonite and manganese garnet in red and white northeasterly dipping cherty tuff are as much as 3 feet thick and appear to be more or less continuous along the strike of the sediments between the two cuts. The manganese lenses are very thinly coated with oxides.

Three occurrences of manganese are known near the head of Widow Creek. The first, on the east side of Widow Creek at an elevation of about 2,100 feet above sea-level, is reported to consist of manganese silicate in a band 1½ to 2 feet thick exposed at two places about 100 feet apart. The second occurrence is west of Widow Creek at an elevation of about 2,600 feet. It is known as the Cottonwood deposit and has been explored by a few shallow open-cuts. The manganese minerals occur in tightly folded beds of cherty tuff and cover an area not more than 100 feet from north to south and

50 feet from east to west. The sediments include light-grey and red cherty tuff and masses of brick-red jasper. Lenses of rhodonite and brown manganese carbonate lie parallel to the bedding of the sediments, and are thinly coated with oxides. Manganese carbonate is not very extensive, and may be a surface alteration of rhodonite. The coating of oxides and the complex folding make it difficult to predict the continuity of the primary manganese minerals between trenches and outcrops. The third occurrence in the Widow Creek area is about half a mile south of Sherk Lake at 3,500 feet above sea-level. It is at the base of the thickest sequence of cherty tuffs in the Sicker group of this area, in beds that appear to be overturned and dip 45 to 50 degrees southwestward. Rhodochrosite and rhodonite occur as irregular masses in a bed of red jasper 2 to 3 feet thick. The jasper has been traced for more than 1,000 feet along the strike, but only locally does it contain manganese. The largest manganese lens seen is a few inches wide and 1 to 2 feet long.

The occurrence at an elevation of 2,700 feet above sea-level, east of the upper part of Wardroper Creek, consists of several lenses of rhodonite and yellow manganiferous chert. The lenses lie parallel to the bedding of the cherty tuff which strikes north 15 degrees west and dips 55 degrees northeastward. Individual lenses are less than a foot thick, but together they total about 10 feet thick and are exposed for about 20 feet along strike.

The Shaw Creek deposit, about half a mile west of Shaw Creek at 1,800 feet elevation, is referred to in old reports as the Black Prince. It has been explored by a number of open-cuts, but these are now difficult to find because they are covered by fallen trees and thick undergrowth that has grown up since the area was logged. Manganese silicates, mainly rhodonite, occur in highly folded red and white cherty tuffs. The rocks form northerly plunging folds, and the manganese lenses, though irregular, appear to follow the bedding. Open-cuts and outcrops expose scattered manganese mineralization over an elongate northwesterly trending area about 300 feet long and 100 feet wide. Some of the manganese lenses are coated with hard black siliceous oxides to a depth of 1 or 2 feet. Analyses of samples of manganese silicates and siliceous oxides from several of these lenses range from 14 to 30 per cent manganese. About 1,000 feet northwest of the main Shaw Creek deposit the cherty tuffs over an area a few hundred feet in diameter are stained with manganese oxides and a few very thin lenses of silicates were seen by the writer.

[References: *Minister of Mines, B.C.*, Ann. Rept., 1918, pp. 296–298; 1919, pp. 237–240. *Canada, Munitions Resources Commission,* Final Report, 1920, pp. 90–95.]

INDEX

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1955

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Plate I. Looking east down Cowichan Lake toward the village of Lake Cowichan at the far end of the lake.

Plate II. Cowichan Lake looking northwest from the hills southeast of Honeymoon Bay—Mount Whymper (right), Mount Landalt (left) on the skyline.

Plate III. Logged-off upper part of Widow Creek looking northward toward Mount Whymper.

Plate IV. Mount Hooper looking westward from the hills at the head of the west fork of Shaw Creek.

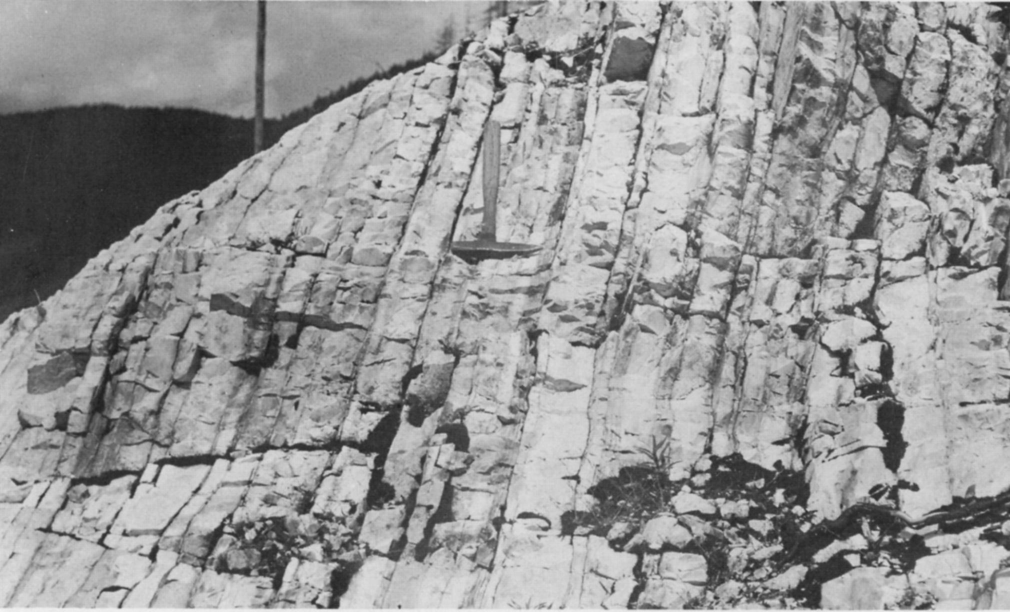

Plate V. Steeply dipping cherty tuffs of the Sicker group exposed on the east slope of Widow Creek about 2 miles north of Youbou.

Plate VI. Tightly folded cherty tuffs of the Sicker group exposed on the western slopes of Widow Creek about 2 miles north of Youbou. The axial plane of the fold dips about 40 degrees away from the observer.

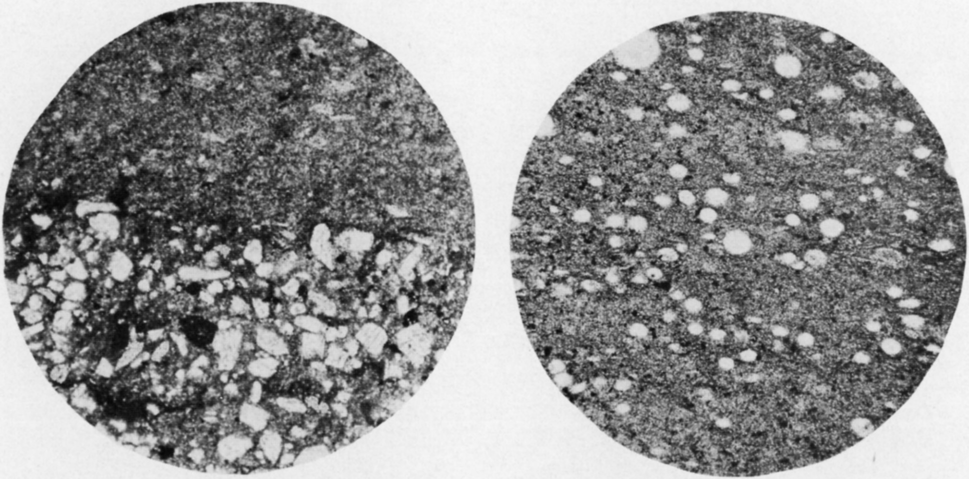

Plate VII. Photomicrographs of cherty tuffs of the Sicker group (magnification ×24). Field on the left shows angular crystals of plagioclase (white) in a cherty and argillaceous matrix. Field on the right shows radiolaria(?) (white spots) in a cherty and argillaceous matrix.

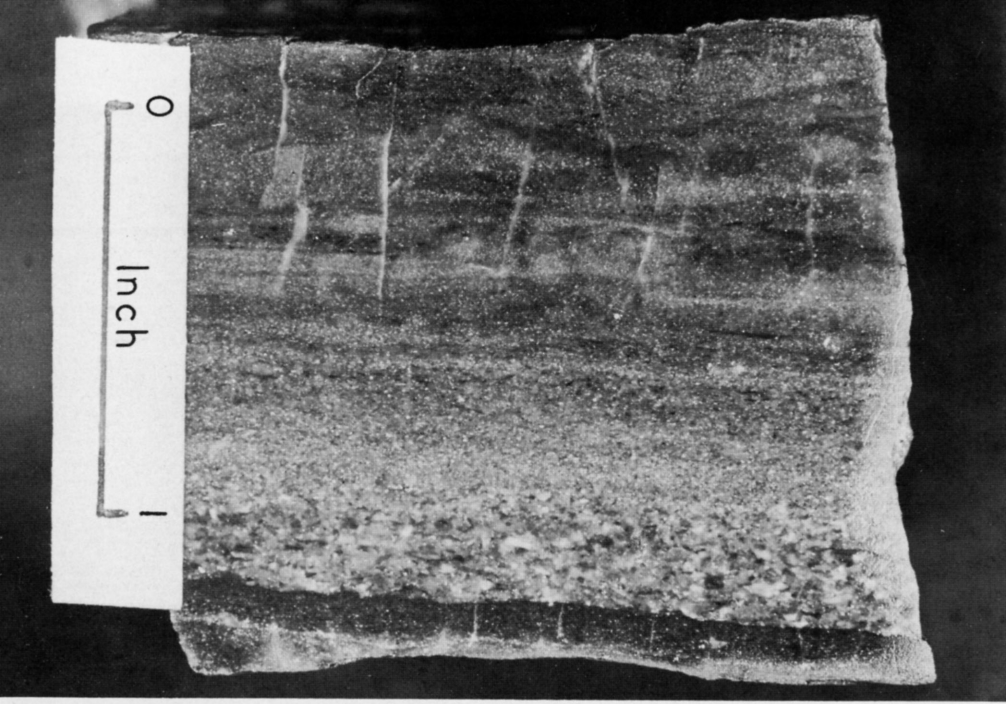

Plate VIII. Cut face of a hand specimen showing graded bedding in siliceous limestone of the Sicker group. The grey relatively coarse calcareous part of the bed grades upward into very fine grained siliceous material and is in sharp contact with the black siliceous top of the bed below.

Plate IX. Volcanic breccia of the Sicker group exposed on the east side of Widow Creek about 2 miles north of Youbou.

Plate X. Pillow basalt of the Franklin Creek volcanics exposed northeast of Mesachie Lake.

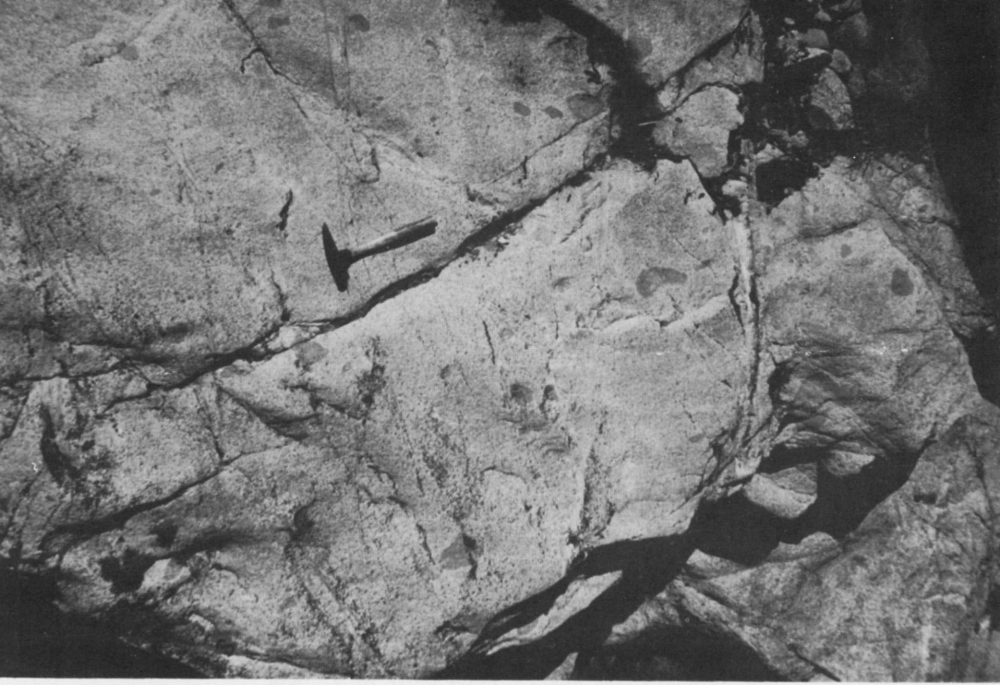

Plate XI. Outcrop of Saanich granodiorite showing rounded mafic inclusions.

Plate XII. Granodiorite dykes cutting metasediments near Saanich granodiorite contact in McKay Creek. Mafic fragment at A appears to have been detached from the wall of the dyke near by.

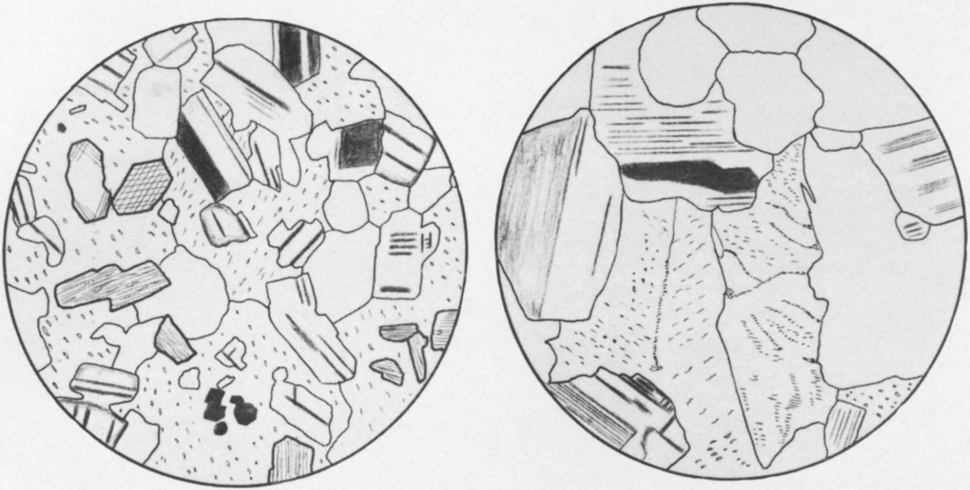

Plate XIII. Camera lucida sketches of the Saanich granodiorite (magnification $\times 14$). Field on the left shows normal granodiorite; field on the right shows aplogranite. Plagioclase showing twinning, quartz unshaded, potash feldspar showing blebs of albite, biotite and hornblende with characteristic cleavage, magnetite black.

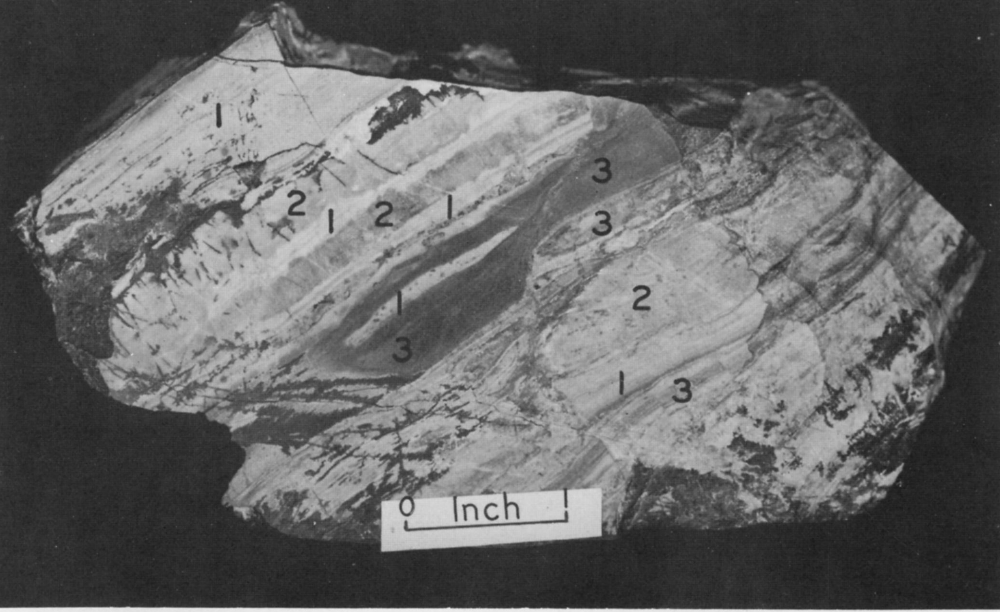

Plate XIV. Cut surface of hand specimen of chert containing manganese showing (1) lenses and irregular cream-coloured beds of chert and yellow manganese silicate, (2) pink beds and lenses containing rhodonite, and (3) brown beds containing manganese garnets. A lens of chert near the centre of the specimen shows radiolaria(?) as small black spots. Black manganese oxides coat the surface of the specimen and line fractures.


LEGEND
Drift and alluvium
TERTIARY (?)
7 Gabbro
UPPER CRETACEOUS
NANAIMO GROUP
6 HASLAM FORMATION: Shale and sandstone
5 BENSON FORMATION: Conglomerate
JURASSIC OR LOWER CRETACEOUS
4 SAANICH GRANODIORITE: Mainly granodiorite and quartz diorite
TRIASSIC
VANCOUVER GROUP
3 CLASTIC SEDIMENTS: Tuffaceous argillite and fine breccia
SUTTON LIMESTONE
2 FRANKLIN CREEK VOLCANICS: 2b - mainly basalt flows, 2c - limestone lens
2d - mainly intrusions of diabase
PERMIAN AND OLDER
SICKER GROUP
SEDIMENTS
1 Mainly limestone
1c Cherty tuff, crystal tuff, and thin bedded sediments
VOLCANICS
1a-1b 1a - mainly amygdaloidal flows 1b - mainly breccia
SYMBOLS
Geological boundary
defined
approximate
assumed
Fault on downthrown side
defined
approximate
assumed
Attitude of bedding
horizontal
inclined
vertical
overturned
Fold axes (approximate)
anticlinal
synclinal
Attitude of schistosity
inclined
vertical
Fossil locality
Glacial striae
Mn Manganese occurrence
x5 Location of granodiorite sample
Mining prospect
Logging road
Railroad
Trail
FIGURE 2
GEOLOGICAL MAP
OF THE
COWICHAN LAKE
AREA
VANCOUVER ISLAND
BRITISH COLUMBIA
1955
Geology by J.T. Fyles
Scale 1 0 1 2 Miles
Contour interval 500 feet
DIAGRAMMATIC STRUCTURAL SECTIONS
Scale 1 0 1 2 Miles
Vertical and horizontal
COWICHAN LAKE
NORTH ARM
MT. HOOPER
HEATHER MTN.
GREEN MTN.
BUTLER PEAK
MT. BUTTLE
MT. SERVICE
EL CAPITAN MTN.
MT. LANDALT
MT. WHYMPER
MT. FRANKLIN
MT. HOLMES
Heath Lake
Delphi Lake
Rheinhart Lake
Mesachie Lake
Beaver L.
Goat I.
Honeymoon Bay
McKenzie Bay
LAKE COWICHAN
MESACHIE LAKE
YOUBOU
49°00'
48°50'
124°30'
124°20'
124°10'
To accompany B.C. Department of Mines Bulletin 37
"Geology of the Cowichan Lake Area"
1955

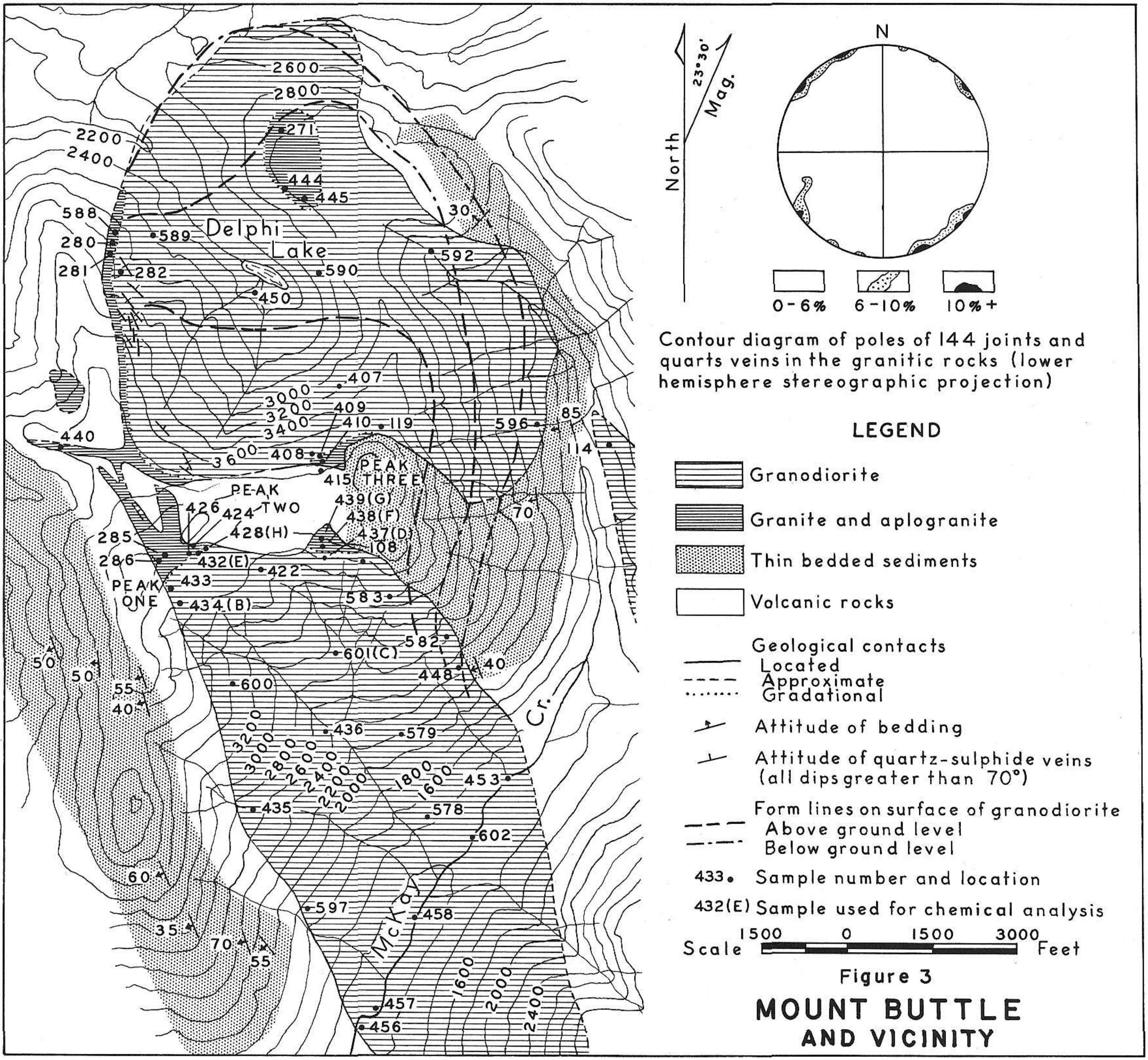

Figure 3

MOUNT BUTTLE AND VICINITY