GEOLOGY OF MOUNT WASHINGTON
VANCOUVER ISLAND, BRITISH COLUMBIA

by

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B.Sc., Queen's University, 1958

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GEOLOGY

We accept this thesis as conforming to the
required standard

THE UNIVERSITY OF BRITISH COLUMBIA
April, 1960
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ABSTRACT

Mount Washington rises abruptly to the west of the Coastal plain of Vancouver Island near Courtenay, British Columbia. It is "Y"-shaped possessing two cirques which face northeast.

The basement rocks of the Mount Washington area consist of several thousand feet of massive basic to intermediate volcanics of the Triassic Vancouver group. A layer composed of gently dipping Upper Cretaceous shales, sandstones, and minor conglomerate and coal overlies the Triassic rocks on the Coastal plain, and outliers of this layer are present on the higher areas west of the plain. Dioritic intrusions cut the Triassic and Upper Cretaceous rocks.

The higher portions of Mount Washington are composed mainly of Upper Cretaceous rocks. These, and the Triassic rocks underlying them have been domed by the intrusion of a centrally located quartz diorite stock. Numerous offshoots of this stock are present in the Upper Cretaceous rocks surrounding it. At its west border there are two breccia pipes.

Copper-bearing quartz veins are present on the west side of the mountain in the vicinity of the stock. These were formed at high temperatures in a near-surface environment.

The distribution of the breccias and sill-like intrusions at Mount Washington suggests that the development of the stock was highly restricted as it moved upward through the Triassic volcanics and that on reaching the Upper Cretaceous sediments
it encountered much less resistance so that it spread laterally to form dykes, sills, and laccoliths(?)

The present investigation provides the only detailed geological mapping done in the Mount Washington–Constitution Hill area, and its contributions are as follows:

(1) additions to the knowledge of the stratigraphy and structure of the rocks in the area;
(2) information on the probable methods of emplacement of the dioritic intrusions, and the relationships among these intrusions;
(3) the existence, extent, and nature of the breccias;
(4) additions to the knowledge of the character of the mineral deposits, including the occurrence of the mineral wehrlite.
ACKNOWLEDGEMENTS

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Discussions with A.F. Buckham of Canadian Collieries Limited and N.D. McKechnie of the B.C. Department of Mines were very helpful in clearing up certain aspects of the geology.

The writer also wishes to thank Dr. W.H. Mathews of the University of British Columbia, under whose supervision the thesis was written, for the valuable advice and aid given during the organizing of the thesis. Additional advice on certain aspects of the geology was obtained from Dr. White, Dr. McTaggart, and Dr. Ross.

Dr. Warren aided the writer in interpreting the results of the stream sediment analyses which were made by his assistants. Dr. Thompson identified the mineral wehrlite in the vein material, and Dr. Rouse, paleobotanist, worked on some samples of fossiliferous sediment.

Mrs. L. Egan who typed the thesis, and Miss P. McFeely who drafted the maps, were of great assistance during the final preparation of the thesis.
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Plate I - Mt. Washington (rear center) and Constitution Hill (rear right) as seen from the Campbell River road on the Coastal plain a few miles west of Courtenay. Photo taken in early winter, looking northwest.
I INTRODUCTION

A. General Statement

During the summers of 1957 and 1958, Noranda Mines Limited and Mt. Washington Copper Company diamond drilled some copper-gold deposits at Mt. Washington near Courtenay on the east side of Vancouver Island. These two companies jointly hold the mineral rights for an area which includes Mt. Washington and extends five miles east of it to Constitution Hill. Their work was a follow-up of exploration carried out previously by other mining companies, and its results were encouraging.

Due to the rugged terrain, no geological mapping of large sections of the mountain was done, though maps of several copper showings were produced. As a result, little was known of the general geology of the mountain. The field work which led to the writing of this thesis was designed to rectify the deficiency in geological mapping of the area. The thesis is concerned mainly with the mountain, and especially with the region of former igneous activity and copper-gold mineralization on the west side of the mountain.

B. Location and Access (see fig.1 and fig.2)

Mt. Washington is 15 miles northwest of Courtenay on Vancouver Island, British Columbia. Most of the area immediately east of Mt. Washington and below 2500 feet in elevation, is traversed by a network of logging roads built by the Comox Logging and Railway Company. Originating at branches of this network are two access jeep roads which were
FIGURE 1 - Location and General Geology of the Mt. Washington - Buttle Lake Area (after Gunning, 1930, slight revisions).
built by Noranda Mines and Mt. Washington Copper Company. The first road terminates at the lower end of the Murex basin and gives access to copper deposits at an elevation of about 2500 feet in Murex creek. The second road penetrates to an elevation of 4000 feet on the West arm where it gives access to an extensive area of copper-gold mineralization.

C. History and Previous Work

1. Mineral Exploration

Panning for gold on the Oyster river, which drains an area including the western slopes of Mt. Washington, was a common occupation during the depression. Some individuals panned four dollars worth of gold per day.

In 1940 the Mackay brothers discovered and staked several gold veins on the Central and West arms of Mt. Washington. In 1941 K.J. Springer did exploratory work on a gold-quartz vein called the No.1 vein (maps 1 and 2).

In 1944 and 1945, Consolidated Mining and Smelting Company did further exploratory work which involved trenching and driving of short tunnels into No.1 vein.

During the summer of 1951, Noranda Mines Limited drilled thirteen X-ray diamond drill holes in an area on the West arm north of No.1 vein and the results were considered to be discouraging.

Mt. Washington Copper Company, which was formed to further explore and develop the deposits of Mt. Washington, built the access road to the West arm in 1956. Some trenching was also carried out in the lower Murex basin where copper mineralization was discovered.
In 1957, Noranda Mines joined Mt. Washington Copper Company in the exploration of the deposits of the Murex basin. A jeep road was built to the Murex showings and a program which included diamond drilling, trenching, geological mapping, a self potential survey, and a soil sampling survey, was carried out.

The drilling revealed a zone of low grade (about 0.5% Cu) copper possibly several hundred feet long, and over 100 feet wide. One self potential anomaly upstream from the first was indicated. Soil sampling showed one area of high readings, but subsequent stripping revealed only sparse sulphides.

In 1958 work was concentrated on the West arm to the north of No.1 vein. Thirteen diamond drill holes were completed. Also, much of the West arm was covered by an electromagnetic survey and anomalous areas were stripped by bulldozer. As a result of this work, a near-surface flat-lying vein, or a flat lying zone containing several veins, was indicated. Its thickness varied from seven to fifteen feet and its grade averaged about 2% Copper. It outcropped at the surface in several places and occurred over a known area of about 250 by 600 feet.

Mt. Washington lies within the land grant area of the E&N railroad which is now owned by the Canadian Pacific Railway Company. Because Noranda Mines and Canadian Pacific Railway Company could not reach agreement on profit splits should a mine be found, exploration work was negligible in 1959. Some electromagnetic work and X-ray drilling carried out just west of Constitution Hill revealed only slight mineralization.

An extensive program of exploration on the West arm and lower east slopes of the mountain is planned for the summer of
1960.
2. Geological Mapping

Very little geological mapping has been done in the immediate area of Mt. Washington. A report by Gunning (1930) on the Buttle Lake area which includes Mt. Washington, contains reference to the Vancouver group rocks near Wolfe Lake (p.61A). It also includes a brief description of the Upper Cretaceous outliers (p.63A) on the Forbidden Plateau, one of which is at Mt. Washington. The origin and nature of the Upper Cretaceous coal-bearing rocks at Cumberland, which is twenty miles east of Mt. Washington, have been described by MacKenzie (1922). These rocks are similar to the sediments on the upper parts of Mt. Washington.

Included in reports by Clapp (1917-Sooke-Duncan area), Buckham (1947-Nanaimo coal field), and Fyles (1955-Cowichan Lake area) are further descriptions of Upper Cretaceous and Triassic rocks which are similar to those found at Mt. Washington.

A map at the scale of 1" = 200' was made of part of the West arm by Consolidated Mining and Smelting Company in 1945. Several detailed maps of the West arm and Murex creek showings were made by Noranda Mines geologists in 1957 and 1958. However, no reasonably complete mapping of any sizable area of the mountain was done.

In 1957 little was known of the geology of the mountain, but, because of its crescent shape and radial fault pattern (map 1), H. Veerman of Noranda Mines proposed that it repre-
sented the ruins of an ancient volcano.¹

D. Scope of the Present Investigation

The writer spent a total of about 35 days (mostly on weekends) in the falls of 1958 and 1959 gathering geological information on the Mt. Washington area. Part of the West arm was mapped at 1" = 400' (map 2). Several traverses were made to the Central and East arms and the information obtained was combined with aerial photograph interpretation to yield a map of the entire mountain at 1" = 1000' (map 1). In the field outcrops were plotted directly on contour maps or recorded in a note book. Several claim survey pegs on the West arm were used for locating outcrops in that area. An altimeter with a maximum error of about 100 feet was used to help locate outcrops on the 1" = 1000' map.

Traverses were made to points of interest in the Mt. Washington-Constitution Hill area. Sufficient information was gathered for a generalized cross section from Mt. Washington to Constitution Hill (cross section 2).

Sediment samples from several streams and rivers of the area were taken for chemical analyses.

Map plotting and microscopic study of rocks collected were done at the University of British Columbia during the winter of 1959-60.

II PHYSIOGRAPHY, CLIMATE, VEGETATION

A. Regional Physical Features (see fig.1 and plates I, II, & III)

Along the east coast of Vancouver Island there is a narrow plain 5 to 25 miles in width. Its average elevation is about 250 feet above sea level and in places it rises abruptly from the sea. Most of the plain has been logged off so that only a few patches of forest remain. It is on this coastal plain that the towns and farms of Vancouver Island are situated.

Numerous elongated ridges up to 100 feet high and 1000 feet long are present on the plain. These ridges trend northwest and are composed of glacial material or of Upper Cretaceous sedimentary rocks. Intervening areas are generally swampy.

Small streams running northwest or southeast and turning east to Georgia Strait, or joining small steep-walled rivers which have their headwaters in the hills to the west, drain the coastal plain.

To the west of the coastal plain the land rises fairly abruptly to an irregular-surfaced plateau averaging about 3500 to 5000 feet in elevation. Most of the plateau is underlain by fairly massive basic volcanic rocks of Triassic age. Small lakes drained by steepwalled streams are common in this area. Scattered mountains rising to maximum heights of about 7000 feet are present on the plateau.

Further inland in the vicinity of Buttle Lake, the country is still more rugged than it is on the plateau.
Plate II - View southwest from Mt. Washington showing Mt. Albert Edward (background) and erosional outlier of Upper Cretaceous sediments (left center). Photo taken in early winter.

Plate III - View east from Mt. Washington towards Constitution Hill and Georgia Strait.
Mountains of over 6000 feet are fairly common and the intervening valleys are steep-walled. Small lakes and permanent ice or snow fields on north-facing slopes, are also fairly common.

**B. Local Physical Features (see fig.2 and map 1)**

In the Mt. Washington area the coastal plain is only four miles wide and ends at Constitution Hill. This hill of quartz diorite porphyry rises abruptly from the plain to more than 1900 feet above sea level. It is elongated in a northwest-southeast direction and along its north and west sides there are steep cliffs several hundred feet high. Parallel to the length of Constitution Hill and on its west side is Wolfe Lake which is 625 feet above sea level.

To the west of Wolfe Lake the surface, most of which is composed of Triassic volcanic rocks, rises to 2500 feet above sea level within two and one-half miles. Numerous ridges here are several hundred feet high and trend northwest-southeast. Several streams draining to the northeast from higher areas traverse this area and most of these such as Murex and MacKay creeks, have fairly steep-walled valleys where they cut through the ridges. This area of ridges is traversed by numerous logging roads and much of it is completely logged off.

From 2500 feet above sea level, Mt. Washington rises quite steeply to the west. It is crescent-shaped with steep inner slopes and more gradual outer slopes. On the upper two thirds of the mountain there are nearly flat-lying Upper
Cretaceous sediments, whereas the lower portions are composed of Triassic volcanics. Mt. Washington can be divided into six distinct physiographic units:

(i) East arm - a ridge composed of nearly flat-lying sediments and a sill which overlie Triassic volcanics (plate V). It trends roughly ENE and is about 1½ miles long by ¾ mile wide. Its highest point is more than 4900 feet above sea level. The north edge of the arm drops off sharply to the Murex basin in a series of steep cliffs up to 700 feet high, which have talus slopes at their lower ends. The south side of the arm is composed of fairly steep slopes but has no large cliffs. To the northeast the arm drops off quite steeply.

(ii) West arm - a ridge whose summit is at above the 4800 foot level and which trends roughly NNW. It is less regular in shape than the East arm, and is composed of Upper Cretaceous sediments overlying Triassic volcanics, both of which are cut by dioritic intrusions. It is about 1¾ miles long by ¾ mile wide. The east edge of the West arm contains a few step-cliffs with small talus slopes at their lower ends, and steep slopes leading down to MacKay Lake. To the north and west this arm drops off much more gently.

(iii) Central arm - a rounded ridge whose crest is 4800 feet above sea level and which is ¾ mile long and runs roughly parallel to the East arm. It is composed of Upper Cretaceous sediments overlying Triassic volcanics and minor dioritic intrusions. It extends NNE from the summit of Mt. Washington, and separates the Murex basin from the MacKay basin.

(iv) MacKay basin - a nearly flat-bottomed, U-shaped valley
FIGURE 2 - Topography of the Mt. Washington - Constitution Hill Area.

Scale: 1" = 4250'  Contour Int.: 500'

Approximate Location of X-Sn. 2
which is opened to the north. It is between the Central arm and the West arm and is about 1000 feet deep. On its floor, which slopes gently to the NNE, are at least two flat areas which slope very gently towards the summit of Mt. Washington. One of these flat areas contains MacKay Lake. The MacKay basin is drained to the NE by the small but steep-walled creek, MacKay creek.

(v) Murex basin - a U-shaped valley which is open to the northeast and is situated between the Central arm and East arm. It is over 1500 feet deep. Its floor slopes to the east but local flat-surfaced areas which slope gently to the west are present. Murex basin is drained by Murex creek which has cut a small but steep-walled, V-shaped valley in its floor.

(vi) Summit - a rounded knob about 1000 feet in diameter which is composed of Upper Cretaceous sediments and dioritic rocks (plate VII). Its north and east edges are cliffs and its maximum height is 5215 feet. Radiating from it are the three arms of Mt. Washington, and the East arm and the West arm are separated from it by the East saddle and the West saddle respectively. Both saddles dip to elevations of approximately 4600 feet.

A sub-radial drainage system consisting of small streams drains the outer slopes of Mt. Washington. To the south and to the west of the mountain there are valleys whose average elevations are about 3200 feet above sea level.

C. Local Climate and Vegetation

During the summer season, bright sunny days and dull
rainy days usually occur in about equal numbers. In the fall the days are cool and the majority of them are rainy. The average yearly precipitation is about forty inches.

Snow sometimes covers the areas above 1500 feet in elevation by November 15 but some years its coming may vary from this date by several weeks. On the upper portions of the hill snow accumulates to depths of over twenty feet so that vegetation is stunted and contorted. The snow does not melt from the upper parts of the hill until the middle of June.

Except for the areas below 3000 feet which have been logged off, the lower parts of Mt. Washington are heavily timbered. Above 4000 feet the trees are smaller and the country has a sub-alpine aspect with open stretches containing heather and small ponds.

Cypress, balsam, Douglas fir, western red cedar, and hemlock are the main tree species on Mt. Washington.
Plate IV - East arm of Mt. Washington taken from the Central arm showing flexed and fractured sediments overlain by a quartz diorite sill (above the dotted line on the right). Photo taken in early winter after snowfall, looking southeast.

Plate V - Summit of Mt. Washington in background. Breccia ridge along right side. Photo taken in early winter after snowfall, looking south from northeast side of Breccia ridge.
III REGIONAL GEOLOGY

A. General Statement

The consolidated and unconsolidated deposits of the general area including Buttle Lake, Campbell River, and Courtenay, fall naturally into five major groups. The lithology and characteristic structures of the five groups are described in the following pages and the extent of their description bears directly on their importance for comparison with the rocks of the Mt. Washington area.

Permian-Triassic volcanic and sedimentary rocks form the first group and are the oldest rocks of the area. They are intruded by the second group of rocks, the Coast Intrusions of Late Jurassic and Early Cretaceous age. The rocks of the first two groups are overlain unconformably by coal-bearing rocks of Late Cretaceous age. These latter rocks are dealt with in some detail in this chapter in order to facilitate their comparison later in the thesis with the capping of sediments on Mt. Washington.

The best exposures of the fourth group of rocks, Late Cretaceous or Tertiary intrusions, are in the thesis area. These rocks are only briefly mentioned in this chapter but are fully described in the chapter entitled "Local Geology." Brief mention is made of Pleistocene and Recent deposits, the fifth group dealt with in this chapter.
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<td>andesite, basalt, tuff, volcanic breccia, limestone, minor quartzite and argillite</td>
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B. Permian-Triassic Volcanic and Sedimentary Rocks

The oldest rocks of the general area outcrop in the region of Buttle Lake. They consist of a thick series of andesitic or basaltic flows, tuffs, and coarse volcanic breccias with two or three interbedded horizons of limestone and minor amounts of quartzite and argillite. They are believed to be Permian in age (Gunning, 1930, p.59A), and likely correspond to the Sicker group of Cowichan Lake described by Fyles (1955, pp.13-19).

The Permian rocks are overlain, apparently conformably, by a great thickness of lavas and fragmentals known as the Vancouver group of Triassic age. These rocks outcrop from near Buttle Lake east to the coastal plain. They have better developed pillow lavas and amygdaloidal and porphyritic flows than do the Permian rocks. They also include breccias, andesites, and rather minor limestone, argillite, and quartzite, and very minor dacite and felsite. They are cut by andesite and diabase dykes, and by a few more acidic dykes. Rocks of the Vancouver group exposed elsewhere on Vancouver Island, have been described by Clapp (1917, pp.93-104, Sooke-Duncan area), and Fyles (1955, pp.19-25, Cowichan Lake area). An extensive description of the composition and primary structures of the Vancouver group rocks is unnecessary in this report since:

(i) there is no doubt that similar rocks at Mt. Washington are of this group so that only a brief comparison need be made.

(ii) in the Mt. Washington area they are nearly all massive
basaltic or andesitic rocks from which the determination of primary structures is very difficult. As a result little information was obtained on such structures.

Several mineral deposits are found in limestone lenses or sheared volcanics of the Vancouver group. Some of those in the Buttle Lake area have been described by Gunning (1930, pp.65A-78A).

The structural trend of the rocks on Vancouver Island is northwest. At Buttle Lake limestone beds in the Permian rocks clearly show broad folds whose limbs dip a maximum of about thirty degrees. West of Buttle Lake there are some vertically dipping shear zones which strike northwest. There are also several faults with similar trends and some possess right lateral displacements of more than one mile. Gunning (1930, p.61A) states that wherever limestone beds occur over considerable distances faulting is observed, but if limestone is absent, the volcanic rocks of the series are sufficiently similar in appearance to render faulting inconspicuous. He concludes however, that the whole Permian section is broken into a number of blocks by numerous faults.

As is the case with the Permian rocks, the similarity in appearance of the Vancouver group volcanics renders faulting within them inconspicuous. They, like the Permian rocks, are likely broken into numerous blocks by northwest trending faults. In the area between Buttle Lake and Mt. Washington the rocks are not strongly folded and generally dip about twenty degrees to the north or northeast. Eight miles southwest of Mt. Washington on Mt. Albert Edward they dip to the
north or northeast at a low angle.

C. Late Jurassic - Early Cretaceous Coast Intrusions

Dykes, stocks, and batholiths referred to the Late Jurassic or Early Cretaceous, intrude the Triassic-Permian rocks. They are believed to be the original source of many of the mineral deposits of the area and are composed of diorite, quartz diorite, granodiorite, or granite.

The east limit of the largest of these intrusions is about five miles southwest of Buttle Lake. The intrusion is at least twenty miles long by ten miles wide and is composed of granodiorite with minor diorite and soda granite. Between the Upper Quinsam and Upper Campbell Rivers there is an intrusive body about eight miles long by five miles wide. It is called the Quinsam granodiorite, but parts of it are diorite or quartz diorite-gabbro, and more acidic phases have been observed. Gunning (1930, p.63A) has suggested that a large area which includes Mt. Washington may be underlain at no great depths by a body of granodiorite. Numerous small intrusions including several a few miles southwest of Mt. Washington which may be upward projections of this body are put in the Coast Intrusion group by Gunning, but he mentions that some of them may be Tertiary in age.

At many localities in the entire Campbell River-Courtenay-Buttle Lake region, where the Permian-Triassic and Upper Cretaceous rocks occur side by side, they appear to be equally deformed. This might indicate that the Puget orogeny of post Late Cretaceous times (White, 1959, p.96) was the
major period of deformation in the entire area and that most of the intrusive rocks, like the rocks at Mt. Washington, were emplaced during this orogeny.

D. Upper Cretaceous Sedimentary Rocks.

1. General Statement and General Extent

A report by Mackenzie (1922) contains descriptions of the rocks of the Comox basin, and a report by Buckham (1947) contains descriptions of the Nanaimo basin rocks. Most of the information in this section was obtained from these two reports.

Coal-bearing Upper Cretaceous rocks of the Nanaimo series underly the east coastal plain of Vancouver Island and outcrop on islands in the Strait of Georgia. They occur in five distinct basins, one of which is the Comox basin extending south from Campbell River to Nanoose Bay. The sediments of Cumberland and upper Mt. Washington belong to this basin.

At the time of deposition of the sediments the Comox basin was co-extensive with the largest of the present day basins— the Nanaimo basin of Nanaimo. Buckham (1947, pp.460-472) has described the rocks of the Nanaimo basin.

In the Nanaimo area the Nanaimo series has a total average thickness of 6,760 feet, and has a maximum thickness of 9,000 feet (Mackenzie, 1922, p.388). At other places on Vancouver Island the total thickness of the series is nearly 10,000 feet.

The six lowest formations of the Nanaimo basin, totalling 1900 feet in thickness, were not formed north of Qualicum river (Buckham, 1947, p.462). Mackenzie (1922, p.389) con-
cludes that the Comox basin rocks could likely be correlated with the Protection formation of the Upper Nanaimo basin.

2. Comox Basin at Cumberland (see fig. 3)

In the Comox basin at Cumberland there are two formations. The lower formation, the Comox formation, lies directly on the Triassic Vancouver group rocks. It underlies a strip of country which is from one and one half to two miles wide and trends southeast from Brown's River to beyond Tsable River. Its southwestern boundary where it is in contact with the Vancouver group volcanics, is irregular. Embayments of the Upper Cretaceous rocks extend back into the Triassic rocks, and outliers of Comox sediments are present to the west of the main area of outcrop of Comox rocks.

The Comox formation is 80 to 1000 feet thick, but its average thickness is 576 feet. It is composed of fine to medium grained grey-white, remarkably homogeneous sandstone, though coarse sandstones and grits are occasionally found. Grey and brownish-grey clay shales and carbonaceous shales occur typically associated with the coal seams. These seams are generally enclosed in layers of shale and the carbonaceous material of the coal consists almost entirely of transported plant remains. In several places there is a basal breccia of heterogeneous texture, formed from angular or rounded fragments of the underlying volcanic rocks. In most localities however, the lowest strata are typically fine-grained. Sandstone, shale, and even shaly coal lie directly on the Triassic rocks. An intraformational conglomerate composed of well rounded argillite, quartzite, quartz, and granitic pebbles is found near the top of the formation in the vicinity of Tsable.
River.

The unconformity between the Comox formation and the Triassic volcanics has considerable relief, amounting to 440 feet (Mackenzie, 1922, p.391). Depressions in this surface were at places filled with angular breccia composed of volcanic rocks, and hills on the surface caused local wedging out of the lower beds of the formation, including some of the lower coal seams. In the vicinity of Cumberland the unconformity dips to the northeast at two to three degrees.

In several localities the Triassic volcanic rocks at the unconformity are decomposed to depths of up to ten feet, probably due to pre-Late Cretaceous weathering.

Overlying the Comox formation is the Trent River formation. It extends from the Strait of Georgia inland about four miles where it overlies, apparently conformably, the Comox formation. It is about 1000 feet thick and is composed dominantly of shale, with minor beds of fine grained sandstone.

3. Types of Structures

The general structure of the Nanaimo rocks of the Comox basin is a monocline of gently northeastward dipping strata, modified in some places by folding, and also by faults of small displacement (Mackenzie, 1922, p.397). The average dip is about five degrees, but northeast dips of up to fifty degrees occur locally, and in some places the rocks dip gently to the west.

In the vicinity of Cumberland, broad shallow folds occur, but these are not as significant with respect to the areas of workable coal as is the irregular Triassic-
**FIGURE 3.**

Stratigraphic Column of the Upper Cretaceous Sediments at Cumberland (after Mackenzie, 1922, p. 393).

**FIGURE 4.** Fault in Lower Nanaimo Series as envisaged by Buckham (1947, p. 467).
Cretaceous unconformity.

Several small normal faults with displacements of a few inches to twenty feet are found in the Cumberland mines. They do not appear to extend into the Triassic basement and are believed by MacKenzie (1927, p.398) to be caused by local anticlinal bulging of the basement rocks causing the overlying layered sediments to be stretched and cracked, and the arches so formed to collapse. Few joints intersect the Comox rocks.

Some structures in the Nanaimo basin rocks (Buckham, 1947, pp.463-466) which are more deformed than the Comox rocks, are pertinent to this thesis. The dominant structural feature of the Nanaimo coal field is the presence of numerous strong faults trending northwest. Most of these faults appear to be rotational thrust faults with their downthrow side to the northeast. Buckham (1947, p.464) records several such faults whose downthrow is zero to possibly 1000 feet.

Buckham (1947, p.466) considers the faults in the Upper Cretaceous rocks of Nanaimo area to be due to post-Late Cretaceous movements of large blocks of the Triassic basement rocks along pre-existing breaks. He states that a north-south fault in the basement rocks, in which the west side has moved upward relative to the east, would rupture the overlying sediments. This rupture would occur along a plane which dips west, the west side moving over the east in a thrust which dies out upward in a sharp roll (fig.4). This, he believes, occurred in the lower part of the Nanaimo section, and caused the shearing and smearing along the
fault surface, of coal from the faulted seams.

E. Late Cretaceous or Tertiary Intrusives:

MacKenzie (1922, p.397) mentions two locations in the Comox basin where sills and cross-cutting bodies of plagioclase porphyry and dacite porphyry intrude the coal seams. At one location some of the coal was improved in quality to a semibituminous nature, but in the other location it was changed "to a mass of impure carbonaceous and sandy material quite valueless as coal."

Many of the so-called Coast Intrusions on Vancouver Island may belong to this group, the lack of cross-cutting relationships with the Upper Cretaceous sediments being due to the absence of such sediments.

F. Pleistocene and Recent Deposits

Deposits of marine and glacio-marine materials up to 300 feet thick cover most of the coastal plain. Except in the area west of Campbell River where the coastal plain widens, they extend inland about six miles. They occur at elevations of up to 500 feet.¹ Glacio-fluvial and ground moraine deposits are found west of the marine deposits to elevations of 1000 to 1500 feet. Further west glacial erosional features predominate.

Deposits along the shores of the Strait of Georgia

include the Recent Salish sediments which consist of shore, deltaic, and fluvial material. These deposits, terraced fluvial deposits, and valley alluvium and colluvium occur locally further inland on the coastal plain.
IV LOCAL GEOLOGY

A. General Statement

This chapter contains descriptions of the rocks, structures, metamorphism and alteration, and mineral deposits of the Mt. Washington-Constition Hill area. Special attention is given to the Upper Cretaceous sedimentary rocks, the intrusions, and the breccias at Mt. Washington. Descriptions of structures characteristic of each of the rock units are included with the lithologic descriptions of such units. Larger scale structures than those characteristic of the individual rock units, and which generally extend from one unit into the other, are described under the heading "Major Structures."

B. Triassic Volcanic Rocks

1. Extent and General Description

The basement rocks of the entire Mt. Washington area are altered volcanic rocks of basaltic or andesitic composition. They are porphyritic and amygdaloidal flows, pillow lavas, breccias, and tuffs belonging to the Vancouver group of Triassic age. The writer did not observe any sediments interlayered with these volcanics.

At Mt. Washington the Vancouver group volcanics form practically all the outcrops below 3800 feet in elevation, but on the Central arm they are found at elevations of up to 4500 feet. Except where small patches of Upper Cretaceous sediments overlie them, they outcrop continuously from Mt.
Washington to the west side of Constitution Hill.

The rocks are typically greenish grey, dark grey, or purplish in colour, fine grained to aphanitic, and weather to a brownish colour. Their similarity in appearance makes the distinction of separate flows or beds almost impossible. Accurate measurement of attitudes is difficult, but in some localities, well developed pillows up to four feet in length reveal their approximate attitudes. Immediately west of Mt. Washington they appear to dip about twenty degrees to the north. In the central portion of MacKay creek they have been observed dipping at angles of up to fifty degrees to the east or west. In several localities near Constitution Hill these rocks dip at fairly low angles of ten to fifteen degrees to the east. It appears true that unless they have been disturbed by local faulting the volcanics of the entire area generally dip fairly gently and generally to the north or northeast.

Randomly scattered white or dark green amygdules from one to six mm. long are common in many flows. White-weathering plagioclase phenocrysts averaging about two mm. in diameter and occurring in clusters are common in others, and many flows are both porphyritic and amygdaloidal. Many flows are composed of well formed pillows with or without phenocrysts and amygdules. Several beds of volcanic breccia and one of medium grained tuff in MacKay creek, have been observed.

Scattered outliers of Upper Cretaceous sediments occurring from Mt. Washington to Constitution Hill reveal that the
Plate VII - Upper Cretaceous shales and sandstones overlain by vertically jointed quartz diorite porphyry on the west side of Constitution Hill.
Triassic-Upper Cretaceous unconformity dips gently to the east and coincides approximately with the present land surface. At a location south of the Summit where the Triassic and Upper Cretaceous rocks are in contact, the Triassic surface of unconformity is decomposed to a white sheared, clayey material to a depth of more than fifteen feet. In Ice creek just west of Constitution Hill there is a similar occurrence of decomposed volcanic rock. However, in another location lower in the same creek the Cretaceous rocks overly unweathered pillow lavas (plate VI). These are the only locations where the exact Upper Cretaceous-Triassic contact was observed. At Mt. Washington the elevation of the unconformity varies from about 3500 feet at the east end of the East arm, to about 4500 feet on the Central arm. On the West arm south of No.2 fault (maps 1 and 2) it appears to be an undulating surface broken in several places by faults.

Jointing is very common in the Triassic rocks. In many localities conspicuous joints dipping gently to the northeast were observed. In one locality northwest of Constitution Hill where a series of pillow lava flows outcrop, similar fractures were found to be bedding plane joints. Crude columnar jointing was also observed in these flows.

In the vicinity of faults the Triassic volcanic rocks are highly fractured.

2. Microscopic Description

The texture of the less altered flow rocks is ophitic, porphyritic, or felted, the main minerals being unzoned or weakly zoned labradorite \( (An_{55-65}) \) or, less
commonly, andesine, and augite or hornblende. Magnetite is everywhere present and in some instances makes up 15% of the rock. Amygdules, when present, may be composed of penninite or may contain calcite, epidote, and quartz. In many of these rocks, composite phenocrysts of plagioclase occur as radiating clusters up to four mm. in diameter.

In most of the rocks plagioclase has been partly saussuritized and the ferromagnesian minerals are altered to chlorite, magnetite, actinolite, and epidote.

C. Upper Cretaceous Sedimentary Rocks
1. General Extent and General Description (see maps 1 and 2; cross sections 1 and 2)

Sandstone, siltstone, shale, impure coal, minor conglomerate, quartzite, and argillite of Late Cretaceous age lie unconformably upon the Triassic volcanics and form the capping of Mt. Washington (map 1). Their maximum thickness on the mountain is at the central part of the East arm where they are approximately 900 feet thick.

Around the outer edge of the capping the sediments are nearly flat-lying. However, in the inner Central arm-West arm area they invariably dip away from MacKay Lake at angles of 5° to 30°. In the vicinities of some faults they are disturbed so that erratic dips of up to 55° may be encountered.

All of these rocks excepting the argillites and quartzites, are similar to the Upper Cretaceous sediments exposed in the Comox basin at Cumberland and described by
MacKenzie (1922, pp. 390-396). The two exceptions occur for the most part over a fairly small area which includes the Central arm and the inner half of the West arm. Most of the rocks in this area are close to dioritic intrusions and are highly indurated.

Outcrops of the Upper Cretaceous rocks on all parts of Mt. Washington, except at the cliffs of the East arm, are very limited. Most of them occur as small moss-covered ledges or as discontinuous patches in stream beds.

Patches of Upper Cretaceous rocks occur between Mt. Washington and Constitution Hill. The western edge of the continuous layer of Upper Cretaceous sediments underlying the Coastal plain is exposed on the west slopes of Constitution Hill where the sediments are cut by a sill of quartz diorite porphyry (plate VII).

2. Description of Rock Types

**Sandstones.** Upper Cretaceous sandstones of various types form the majority of outcrops on the upper parts of Mt. Washington. Most of them are not true sandstones. They are feldspathic, argillaceous, or lithic sandstones, and many of the more highly indurated types are greywackes. Grain sizes in the different types vary from very fine to coarse. Most are light grey or bluish grey and bedding is very faint or absent. Their compositions vary considerably. Some are composed chiefly of quartz with minor argillaceous matrix whereas in others the argillaceous matrix dominates. Most, however, are composed of a homogeneous mixture consisting of grains of quartz, feldspar, and rock fragments set in a matrix
of recrystallized argillaceous, slightly carbonaceous material. Primary calcite is extremely rare.

Rocks typical of the sandstones found at several places including the Summit, are white, medium grey, or bluish-grey, massive, and medium to fine grained. Under the microscope they are observed to contain angular elongated grains of strained quartz (45% average), clouded orthoclase, oligoclase, or andesine, (10% average), and fragments of chert, shale, basic volcanic rocks, and granite (15% average). These are in a matrix which includes sericite, chlorite, biotite, iron oxides, pyrite, organic material, and minor amounts of apatite, zircon, and sphene.

Several outcrops of grey or tan coloured, medium to coarse grained, massive argillaceous sandstone occur on the outer portions of the West arm and on the west side of Constitution Hill. Their constituents are similar to those of the finer grained varieties described above, but the matrix in some is greater than 50% of the rock and does not contain organic material. flakes and elongated fragments of shale derived from the underlying rocks by weathering are common in the coarse sandstones.

Carbonaceous Shales and Siltstones. Outcrops of dark grey to black shale, generally interbedded with lighter grey-brown siltstone, are common in areas underlain by unmetamorphosed Upper Cretaceous rocks. Some of the shales are very fissile and a few contain pyrite nodules. Both the shales and the siltstones contain organic material, and carbonized plant remains (plate VIII) lying parallel to bedding planes are
readily seen. Beds of low grade coal are known to outcrop in two localities on Mt. Washington.

Under the microscope these rocks are observed to contain layers and lenses of silty material. This consists of angular to sub-rounded quartz, rock fragments, and feldspar, in a matrix of chlorite-clay mineral-sericite plus carbonaceous material and iron oxide. These are enclosed within dark, extremely fine grained organic-rich argillaceous material containing scattered, small angular grains of quartz. In some places the silty layers contain minor amounts of calcite. Pyrite nodules, if present, are composed of composite masses of euhedral crystals.

Conglomerates and Breccias. Intraformational conglomerates were noted at only two localities. One is south of the Summit, and one is on the East arm. At the first mentioned location the thickness of the conglomerate is at least twenty feet and it occurs approximately 100 feet above the Upper Cretaceous-Triassic unconformity.

These conglomerates are greenish-grey and are composed of well rounded chert, granite, greenstone, quartz and shale pebbles averaging \( \frac{3}{4} \) inch in diameter. Their matrixes are composed of coarse grained sand and argillaceous material.

Basal breccia composed of angular to rounded fragments of the underlying Triassic volcanics was observed near the junction of Murex and MacKay creeks. It is dark green or purplish in colour and similar in appearance to some of the Triassic volcanic breccias. However, it contains lenses of coarse sandstone and is very local in occurrence, having
formed in a depression on the Upper Cretaceous-Triassic unconformity.

**Argillites and Quartzites.** Many of the sedimentary rocks at Mt. Washington have been highly indurated and re-crystallized. This is especially true of rocks in the inner West arm - Central arm area. Argillites and quartzites are so common in the vicinity of the mineral deposits that they will be described here. Other less common altered and metamorphosed rocks are described later under the heading Metamorphism and Alteration.

The typical argillites are dark grey or black, aphanitic, tough and massive, and break conchoidally. Many of them are laminated but these laminae have a melted appearance.

Under the microscope the minerals are observed to interlock with one another in an extremely fine grained mat. Bedding is visible, but it is not as distinct as it is in the shales. Quartz grains (approximately 25%), chlorite (approximately 20%), sericite (approximately 20%), biotite (approximately 25%), and opaques (approximately 10%–mainly pyrite), are present. Veinlets of quartz, pyrite, and biotite cut across the bedding.

Quartzitic rocks are found only within the general area of the Upper Cretaceous-Triassic unconformity and are obviously the results of silicification and recrystallization of sandstones.

These rocks are fine to coarse grained, sugary textured, greyish-fawn coloured, and contain glassy quartz
grains set in a dense matrix. In thin section they are observed to contain interlocking fragments of quartz and some grains of silicified feldspar, and various rock types. Veinlets of fine grained quartz invariably cross cut the rock. The matrix is mainly quartz but minor amounts of biotite, chlorite, sericite, pyrite, and iron oxides are generally present. Some of these rocks may have originally been basal quartz sandstones.

3. Description of Some Specific Occurrences (see maps 1 and 2)

General Statement. In order to illustrate the characteristics of the outcrops of Upper Cretaceous rocks found at the Mt. Washington-Constitution Hill area several specific occurrences are described in this section. On the basis of the nature of the occurrences some inferences are made regarding their stratigraphy.

On West Arm. Nearly flat-lying interlayered shales and siltstones are found in Pyrite creek and west of No.1 saddle along No.1 fault at elevations of about 3750 feet. In both localities the underlying rock is a bluish-grey, medium to coarse-grained well indurated and rusty sandstone. Since Triassic volcanic rocks occur about fifty feet below the sandstone and since this type of sandstone overlies the Triassic rocks south of the Summit, it is believed to be the lowest rock of the Upper Cretaceous section at most parts of Mt. Washington. This belief is supported by the occurrence of several outcrops of quartzite—silicified recrystallized sandstone—directly above the Triassic rocks.
on the inner West arm and on the Central arm. It is also supported by the occurrence of small patches of sandstone lying on the Triassic rocks on the north slopes of Mt. Washington.

A bed of low grade coal dipping gently to the west and enclosed in beds of sandstone is exposed at an elevation of 4180 feet on the outer part of the West arm, 1000 feet north of No.1 fault.

Summit and Central Arm. Grey-white fine to medium grained massive, homogeneous sandstone at least 300 feet thick occurs at the Summit. It dips to the south at about twenty degrees. Near its contact with quartz diorite porphyry it is dark grey and slightly foliated.

On the Central arm, argillites, quartzites, and other varieties of silicified shale and sandstone underly a north extension of the sandstone beds exposed at the Summit.

East Arm. Due to its inaccessibility, the East arm was not mapped in detail. It contains approximately 900 feet of Upper Cretaceous sediments which generally dip gently to the south. The topmost bed is exposed at the summit of the arm and is composed of white sandstone. Its maximum possible thickness is about twenty feet for outcrops of bluish shale occur at that distance below it. Similar shale and some sandstone outcrop along the entire top surface of the arm to the east of its summit, and argillites and quartzitic sandstones outcrop at the lower east end of the arm.

Samples from the talus slopes on the north edge of the
East arm consist of well indurated silty and carbonaceous shales and grey-blue sandstones, and coaly material. All three rocks contain plant remains. A sample of conglomerate was also obtained. Outcrops at the upper end of the talus slope, probably approximately 300 feet above the Upper Cretaceous-Triassic unconformity, consist of beds of carbonaceous shale and carbonaceous sandstone.

**Vicinity of Constitution Hill.** A small outlier of Upper Cretaceous shale and sandstone overlain by a twenty foot thick remnant of a dioritic sill occurs at about 1500 feet in elevation in Ice creek west of the north end of Constitution Hill. The sediments dip to the east at fifteen to twenty-five degrees. Similar but larger outcrops of sediments and diorite occur to the south of this outlier.

On the west side of Constitution Hill sandstone, shales and coaly beds totalling approximately 150 feet in thickness overly Triassic volcanics. They are overlain, in turn, by a sill of quartz diorite porphyry (cross section 2 and plate VII). These sediments dip to the east at about ten degrees where they underly the sill. However, about fifty feet directly below the sill they dip 35° east and lower still they dip 65° to the east.

About 1000 feet northeast of Constitution Hill the Upper Cretaceous sandstones and shales dip 60° to the east but at the northeast edge of the hill where they are overlain conformably by the sill, they dip gently to the east.

In Conglomerate creek about one mile north of Constitution Hill the sediments dip twelve degrees eastward.
4. Correlation With the Comox Formation

Gunning (1930, p.65A) concluded that the Mt. Washington sediments represent an outlier of the Comox basin sediments because of their lithologic similarity and proximity to the coastal plain sediments of the Comox basin.

At both Cumberland (fig.3) and Mt. Washington, the lower beds are sandstones, carbonaceous sandstones, carbonaceous shales, and coal beds. From approximately two hundred to five hundred feet above their base, sandstone is the main rock. The coal seams occurring in this part of the section at Cumberland, (to which the rocks of the Summit should correspond) were not seen at Mt. Washington, possibly because of their absence. It could, however, also be due to the fact that traverses by the writer from the Summit to the West arm along the top of the East saddle were nearly in the plane of bedding of the sediments so that close observation of the cross section could not be made.

Since the maximum recorded thickness of the Comox formation at Cumberland is 1000 feet but its average thickness is only 576 feet, and since the East arm sediments are a maximum of approximately 900 feet thick, it is likely that the silty shales and sandstones on the upper parts of the East arm are within the Trent River formation.

D. Late Cretaceous or Tertiary Intrusions
1. Rock Types and General Extent (see maps 1 and 2; cross sections 1 and 2)
Sills, dykes and irregular bodies of quartz diorite porphyry and quartz diorite intrude the Triassic and Upper Cretaceous rocks of the area.

At Mt. Washington there is a centrally located sub-jacent body of quartz diorite and quartz diorite porphyry. It is likely a stock and will be referred to as such in this thesis. Apophyses of this body, dykes, and sills, all of quartz diorite porphyry, occur in the rocks surrounding the central intrusion.

Dykes of quartz diorite porphyry in the Triassic rocks, and sills of similar composition in the Upper Cretaceous outliers, are found between Mt. Washington and Constitution Hill. The upper five sixths of Constitution Hill is composed of quartz diorite porphyry.

The dominant texture of the dioritic intrusions is porphyritic but the interior of the Mt. Washington stock is composed of equigranular quartz diorite.

A detailed study of variations in the compositions of the intrusive rocks was not made by the writer. However, determinations made on plagioclase crystals from the intrusions suggest that slight differentiation has occurred in the stock as it was intruded. Some zones contained in crystals from the interior of the stock are more albitic than any of the zones in those of the dykes, sills or breccias (pages 42, 43, 64, 65). Complex zoning in the crystals is believed to be indicative of unstable conditions, such as those of temperature, pressure, and volatile content, which existed in the magmas.
Some of the intrusions which contain quartz only in their groundmasses may have formed at an early stage of the intrusion of the stock.

In many localities, and especially on the West arm of Mt. Washington, these intrusions are altered to some degree. These altered varieties will be described later under the section entitled "Alteration".

2. Equigranular Variety

Equigranular quartz diorite is found only within the central portions of the stock and in some of the more deep seated dykes.

In the hand specimen it is greenish-grey or light grey, medium grained, and contains plagioclase, quartz, hornblende, and biotite crystals which average two to five mm. in length. Some hornblende crystals are ten mm. in length.

In thin section (plate IX), the rock is observed to contain about 65% highly zoned and twinned plagioclase (An_{18-52}) as euhedral or incomplete subhedral crystals, 8% poikilitic hornblende (Z\^C = 17^\circ; pleochroism-X = yellow brown, Y = medium brown-green, Z = medium brown; absorption - Z>Y>X) as ragged euhedral to subhedral crystals, 4% euhedral biotite (pleochroism-X = pale yellow, Y and Z = mahogany brown), 20% interstitial and slightly strained quartz, and accessory hematite, magnetite, ilmenite, apatite and sphene.

Minor sericite occurs as a replacement of plagioclase in some of its inner and intermediate zones and along fractures and cleavage planes within it. A minor amount of chlorite replaces some of the biotite.
Plate VIII - Photomicrograph of carbonaceous siltstone, 
(crossed nicols, x16)

Plate IX - Photomicrograph of equigranular quartz diorite 
from the central portion of the Mt. Washington 
stock near MacKay Lake, (crossed nicols, x16)
Small inclusions of quartz and plagioclase are scattered throughout hornblende crystals.

Plagioclase crystals exhibit distinct albite and combination carlsbad-albite twinning and are concentrically zoned. The outer edges of most crystals are irregular in shape due to resorption or recrystallization. One crystal studied possesses seven zones. The outermost zone consists of at least four minor normal type zones and its range is approximately from $\text{An}_{18}$ to $\text{An}_{52}$. The next four zones are thinner than the first and are also of the normal type. Their ranges are from about $\text{An}_{40}$ to $\text{An}_{50}$. The sixth zone has an invariable composition of about $\text{An}_{45}$ and is slightly larger than the previous four. The radius of the innermost zone of the crystal is similar in length to that of the sixth zone. However, this core is zoned reversely, and its range is approximately $\text{An}_{47}$ to $\text{An}_{40}$.

3. Porphyritic Varieties

Quartz diorite porphyries form the bulk of the intrusions in the Mt. Washington-Constitution Hill area. The upper and outer portions of the stock, its apophyses, and practically all the dykes and sills are porphyritic. On later pages these rocks, which are described below, will be referred to as the porphyries.

Unaltered porphyry is light grey or light greenish-grey. Thirty to sixty percent of the rock consists to a large extent of nearly equant phenocrysts of white plagioclase. Clear phenocrysts of quartz two to five mm. in diameter and elongate, dark green hornblende crystals two to ten mm. long
are commonly scattered throughout the rock. However, in some of the intrusions, quartz is present only in the groundmass. Alignment of phenocrysts, especially hornblende, is visible in many outcrops.

Microscopic observations reveal that these rocks are nearly identical in mineral composition to the equigranular variety. Highly zoned and twinned plagioclase (An$_{22-52}$), poikilitic hornblende, and, in most cases, quartz, occur as phenocrysts (plate X). The matrix constitutes about 50% of most of the rocks and is very fine grained to aphanitic hypautomorphic granular, and contains quartz and plagioclase with shreds of hornblende. Apatite, sphene, and opaques are present throughout the groundmass and as minute inclusions in the phenocrysts. Minor biotite may be primary but minor amounts of chlorite and epidote occur as alteration products of hornblende and plagioclase. Sericite replaces certain zones, fractures, and cleavage planes within plagioclase phenocrysts.

Many quartz phenocrysts are rounded (plate X) and some possess embayments caused by resorption. Smaller grains of quartz replace some plagioclase crystals around their outer edges, or they may even form veinlets which cut across the crystals.

Some plagioclase is present as broken crystal fragments. One oscillatory-zoned plagioclase crystal studied consists of six major similar-sized zones, many of which contain several smaller zones. The outermost of the major zones exhibits normal zoning and its range is from approximately An$_{22}$ to
Plate X - Photomicrograph of quartz diorite porphyry from a dyke on the West arm, (crossed nicols, x16)

Plate XI - Photomicrograph of sub-cataclastic quartz diorite porphyry from near No.1 fault, (crossed nicols, x16)
The next two major zones have ranges of from about $An_{45}^0$ to $An_{50}^0$. The fourth zone is of the normal type and contains a small unconformity within it. It has a range of approximately $An_{30}^0$ to $An_{50}^0$. Between the fourth and fifth zones is a distinct and irregular unconformity. The fifth zone is zoned reversely with a range of approximately $An_{50}^0$ to $An_{45}^0$. The core shows normal zoning and ranges from approximately $An_{50}^0$ to $An_{52}^0$.

A distinct variety of porphyry is found in some of the dykes and sills on the upper parts of Mt. Washington. It is found less perfectly developed in apophyses of the stock, and in net veins cutting the brecciated rocks around the fringes of the stock. It is mineralogically identical to the common porphyry but most of its phenocrysts are broken and many are partially resorbed, and in some instances they are crowded together in a scanty matrix (plate XI). The writer believes that this variety of porphyry was forcefully intruded or was intruded along active faults. It will be referred to on later pages as "sub-cataclastic" porphyry.

Another variety of porphyry which is darker coloured than the normal variety is found at some locations near the border and in apophyses of the stock, and near the contacts in some other intrusions. Its brownish-grey colour is due to the presence of numerous foreign inclusions in the matrix. On later pages porphyries of this type will be referred to as "contaminated" porphyries. Biotitized porphyries on the West arm have a somewhat similar appearance.
4. Descriptions of Some Specific Occurrences

Mt. Washington "stock". The Mt. Washington stock may be an upward projection of the large buried body of granodiorite whose presence was proposed by Gunning (p. 18). This centrally-located body of quartz diorite is exposed over an area of about 2000 by at least 5000 feet (map 1). Its outer portions are porphyritic whereas its interior is equigranular. At places along its west side where it is in contact with the Triassic volcanic rocks the host rocks are brecciated, and the network of fractures so formed is filled with porphyritic quartz diorite which has some characteristics of the sub-cataclastic porphyries—some rounded and broken crystals. In many places near its outer contacts the diorite of the stock is brecciated and network of fractures formed is filled with poikilitic actinolitic hornblende ($Z^\wedge C = 16^\circ$; pleochroism-$Y =$ greenish yellow-brown, $X =$ pale yellow-brown, $Z =$ brownish green; absorption-$Y \geq Z>X$). These contact zones and network vein quartz diorites exhibit seriate texture, their largest crystals being of similar size to the phenocrysts of the normal porphyritic variety.

The exact northern limit of the stock has not been definitely established. At an elevation of 2700 feet in MacKay creek quartz diorite is in vertical contact with Triassic volcanic rocks in an outcrop approximately twenty feet in diameter. This is likely the north contact of the stock. Lower in the creek only Triassic rocks are found, and the closest outcrop upstream from this contact is composed of equigranular quartz diorite. The quartz diorite at the
contact is chilled and is medium fine grained. This is the only location found where the dioritic rocks do not contain crystals of at least two millimeters size.

The Triassic-porphyry contact in at least one place on the Central arm is nearly horizontal. On the West arm the contact zone is in places composed of xenoliths of country rock and the network veins mentioned previously. The results of several drill holes collared in the areas a few hundred feet east and several hundred feet north of No.1 saddle suggest that the stock contact in these vicinities is steep. Several apophyses of the stock composed of contaminated porphyry intrude the Upper Cretaceous rocks on the Central arm.

Deduction of the thickness of the Upper Cretaceous sediments at Mt. Washington during the intrusion of the stock could reveal the approximate minimum depth of overburden existing above the stock when it was intruded. The Comox and Trent River formations average approximately 1600 feet in thickness (p. 21). Richardson (1872, p. 51) reports 4912 feet of sediments overlying these formations near Denman Island a few miles south of Courtenay and the Nanaimo basin sediments reach 10,000 feet in thickness (p. 19). These facts could be interpreted as indicating that the cover of sediments was thick when the stock was intruded. However, foundering of the block on the east side of No. 5 fault and between No. 1 and No. 3 faults may have occurred since the main movement on No. 5 fault at this location could be interpreted as having
been dilational (p.109). Foundering of the roofs over intrusions is suggested by Noble (1952, p.55) as indicating that the intrusions reached near to the surface so that the present position of the upper part of the Mt. Washington stock may have been very near to the surface when the stock was emplaced. If this is true then it follows that the Upper Cretaceous sediments must have been thin during the intrusion of the stock.

In the outer portions of the stock especially, it is traversed by numerous joints, but no definite pattern was observed.

**West Arm Intrusions.** Dykes, sills, and irregular bodies of quartz diorite porphyry intrude the Upper Cretaceous sediments of the West arm. Along Pyrrhotite creek there are several bodies of porphyry which appear to be faulted sills and/or parts of a sheared dyke (map 1). Many of these, and other intrusions on the inner West arm exhibit some rounded, resorbed, and broken crystals. However, an intrusion in Pyrrhotite creek and many porphyry bodies along No.1 fault exhibit sub-cataclastic structure. To the north and to the east of No.2 fault the Triassic volcanic rocks contain some porphyry dykes.

At most localities on the outer slopes of the West arm where the Upper Cretaceous-porphyry contacts have been observed, they are concordant. However, vertical contacts have been observed. The porphyry intrusions in this area appear to be fingers of the thicker and more continuous Main sill described in the following pages.
Main Sill. The Main sill is the largest intrusion, other than the stock, at Mt. Washington. Its shape is not fully known, partly because the present erosional surface is below its original upper contacts, and it may not be a sill. However, it appears to be mainly flat-lying and extends from the top of the East arm through the East saddle, across the Summit, and possibly to the north end of the West arm where it may wedge out in several fingers. Because much of the sill has been eroded away, its original extent is unknown. It is composed of porphyry, and at some places near its contacts with older rocks, of contaminated or biotitized porphyry.

A sample taken from the East arm contains quartz only in its matrix. Otherwise it is a typical porphyry. Also found at the East arm are small round masses of porphyry about two inches in diameter which stand about 3/8" above the porphyry enclosing it but appeared to be identical to it. Two hundred feet southwest of the Summit the sill contains what appear to be widely scattered amygdules of chlorite 3/8" in diameter.

On the lower west side of the Summit vertical prismatic jointing is very conspicuous and the rock contains some small inclusions of shale.

At the East saddle the Main sill possesses several unusual features. Upper Cretaceous sediments on the east side of No. 4 fault (map 1) which crosses the saddle have been displaced downward several hundred feet with respect to those on the west side. However, the Main sill steps up from the west to the east sides of the saddle. On the inner west side
of the saddle where the Upper Cretaceous sediments are flexed downward, the Main sill cuts steeply across their bedding planes (plate IV) and several hundred feet further to the east at the summit of the East arm the lower contact of the sill is foliated. Within the saddle the porphyry of the sill possesses well developed prismatic joints.

**Murex Creek Dyke.** A dyke of quartz diorite porphyry 40 feet wide by at least 2000 feet long and trending ENE, cuts the Triassic volcanic rocks at about the 2500 foot level in Murex creek (map 1). It is of similar composition to the common quartz diorite porphyries but its hornblende is highly altered to chlorite, its plagioclase is somewhat altered to calcite, epidote and sericite, and it contains poikilitic euhedral pyrite crystals. Many of its quartz phenocrysts are rounded.

**Ice Creek Dyke and Sills.** A sill of quartz diorite porphyry overlies Upper Cretaceous sandstone at the 1500 foot level in Ice creek ½ mile west of Constitution Hill. Other larger outcrops of porphyry sills overlying sandstones are present in the general area from ½ to five miles south of it.

At 2000 feet in elevation in Ice creek a vertical dyke of similar porphyry twenty feet wide cuts Triassic rocks.

**Constitution Hill** (see plate III, cross section 2). An elongate body of quartz diorite porphyry about eight miles long and one and one half miles wide occurs in the Upper Cretaceous rocks at Constitution Hill. In places it is at least 1000 feet thick.

In mineral composition and general appearance, the
interior portions of the intrusion are identical to most of the normal porphyries. At its northwest border however, its groundmass is aphanitic and almost glassy.

At an elevation of about 850 feet on the northwest side of Constitution Hill the porphyry concordantly overlies Upper Cretaceous sediments (plate VII). One thousand feet further south it extends below Wolfe Lake which is at an elevation of only 624 feet. The Upper Cretaceous rocks at the first locality strike approximately north-south and are only about 150 feet thick. The intrusion must either extend downward into the Triassic volcanics, or else there must be a fault between the two locations. Such a fault almost certainly exists (p.85).

Vertical prismatic joints a few to several hundred feet long are the main structural features of the Constitution Hill porphyry. On the summit of Constitution Hill shrinkage(?) joints divide the rock into blocks resembling equant loaves of bread (plate XVII). At the north end of the hill, well-developed nearly flat-lying joints which are slightly arched, occur within the porphyry.

5. Age and Correlation Among the Intrusions Within the Area

Clapp (1917, p.304) has correlated a body of dacite porphyry which cuts the Comox sandstone near Cumberland and which is similar to the intrusions of the Mt. Washington area, with the Early Oligocene intrusives of the Sooke area of southeast Vancouver Island. Gunning (1930, p.64A) considers that in all probability all of the intrusive rocks of the Mt. Washington and Goss Lake areas should be placed in the same
period.

The similarity in mineral composition of all the intrusions in the Mt. Washington-Constitution Hill area suggests a common source. Their textural or structural differences appear to be due to their different physical forms and methods of emplacement.

E. Breccias and Fractured and Brecciated Rocks (see maps 1 and 2; cross sections 1 and 2)

1. General Statement.

Breccias and fractured and brecciated rocks closely related in origin and age to the dioritic intrusions are found in large quantities at Mt. Washington. They occur in a zone which averages 1000 feet in width and extends more than 4000 feet north of Glacier Lake along the West arm. This zone coincides approximately with the position of the Upper Cretaceous-Triassic unconformity. The rocks are readily divided into three types on the basis of their physical characteristics.

Both of the first two types are composed of rock fragments set in a comminuted matrix. However, whereas the first type, which will be named the Murray breccia, varies greatly in appearance from place to place and its matrix is generally biotite-rich, most of the second type, which will be named the Washington breccia, is similar in appearance and contains a magnetite-rich matrix. Also, fragments of the Murray breccia may be well rounded or angular and very few are slab-shaped whereas many fragments of the Washington
breccia are slab-shaped and not many are well rounded.

Nearly continuous outcrops of the Murray breccia are found along the entire length of Breccia ridge at elevations of greater than 4600 feet. These outcrops are almost certainly parts of a pipe-shaped mass. A small body of breccia similar to the Murray breccia is present in Glacier creek.

The Washington breccia outcrops as a pipe-shaped mass along much of the east edge of Breccia ridge where it is in near-vertical contact with the Murray breccia.

The Murray breccia is older than the Washington breccia and appears to have been formed largely by intrusion above the Mt. Washington stock. Rock bursting and collapse of rock within a dilational fracture which was formed or reactivated by the intrusion of the stock may have been largely responsible for the development of the Washington breccia.

Fractured and brecciated rocks which constitute the third type of rocks considered in this section are found to the east and north of the Murray and Washington breccias in a zone which extends along the west side of the stock. The outer limits of this zone are arbitrarily chosen. Rocks of all types are present in the zone, but porphyry is most common. Small areas of brecciated rocks and rocks cross cut by net veinlets of porphyry or of several types of minerals constitute most of the zone.

The origins of the three types of rocks described in this section are dealt with in a later chapter entitled "Origin of the Breccias".
2. Murray Breccia

Field Occurrence and Description. Murray breccia outcrops almost continuously for a length of more than 2000 feet on Breccia ridge (plate XII). The outline of the outer limit of the exposures is that of an elongated oval trending NNW parallel to the length of the ridge. The maximum known width of the breccia zone is approximately 600 feet.

To the east it is in near vertical contact with Washington breccia (see p.60). On its north it is in vertical contact with biotitized porphyry. At a location on the west side of the ridge near the northern limit of the breccia it is in contact with metamorphosed argillite. There is a possibility that this argillite could be an inclusion. However, the contact likely represents the western limit of the zone in this particular location since the only indications of bedrock on the upper portions of the slopes to the west of the entire zone are little disturbed boulders of porphyry. On its south and southeast sides the zone is almost certainly in contact with biotitized porphyry.

At an elevation of about 4400 feet in Glacier creek, a layer of breccia similar in appearance to the Murray breccia and possibly thirty feet thick, overlies green-grey porphyry. At one place the contact appears to dip about 35° southeast. Other smaller zones of similar breccia occur about two hundred feet upstream.

The general appearance of the Murray breccia varies from place to place on Breccia ridge. Some outcrops contain fragments of porphyry only, whereas others are composed of a
Plate XII - Breccia ridge taken from the Central arm, looking northwest.

Plate XIII - Rubbly Murray breccia. Sandstone fragment above knife, porphyry fragment above and to right of knife. Dark-rimmed sediments throughout.
heterogeneous mixture of shale, sandstone, and porphyry fragments. The matrixes of the breccias vary in amount and colour. These colour differences are due to the different proportions of the various constituents and to the varying degrees of alteration. Despite their wide variations in appearance, there appear to be gradations among the different types.

A rubbly Murray breccia is well exposed about 200 feet south of the small pond on the ridge. It is grey and contains angular and rounded fragments of white porphyry, grey sandstone, dark grey shale, and broken crystals of quartz and feldspar (plate XIII). The rock fragments vary in size from microscopic to about six inches in diameter. Most of the fragments less than five mm. in size are plagioclase and quartz. The shale and sandstone fragments possess dark altered rims up to $\frac{3}{4}$ of an inch thick, whereas the porphyry fragments appear to be unaltered. No layering was observed in this type of breccia.

The breccia described above appears to grade to the south into another type of breccia which possesses a more dioritic appearance (plate XIV). It contains fragments of porphyry almost exclusively and most of these are rounded to some degree. It also contains dioritic material which occurs in streaks, some of which are arranged in a swirling manner. Some hornblende crystals are found in the matrix. In some places this breccia contains a very crude but discontinuous layering which is partly expressed by the regular arrangement of dioritic streaks, and partly by the different
Plate XIV - Dioritic Murray breccia with white dioritic streaks and porphyry fragments. Swirled streaks on right.

Plate XV - Contact of pebbly Murray breccia with argillite block at south end of Breccia ridge.
proportions of porphyry fragments within adjacent layers. However, even within the individual indistinct layers the fragment content varies considerably. The layering varies in dip from 45° SSW to 75° SSW within 100 feet in a single outcrop. In the adjacent outcrop similar layering varies in dip from 40° SSW to 80° NNE, and in an outcrop immediately to the south of the last the layering is bent and contorted and varies in dip from horizontal to vertical within a few feet. One layer dipping about 40° SSW contains a concentration of round fragments of porphyry in the vicinity of its lower but indistinct contact with similar but finer grained breccia. The contact is drag folded. This fold is about six inches wide and the pebbles appear to be swirled about in its vicinity.

Most of the Murray breccia of the north, west and south portions of the ridge is somewhat similar in appearance to conglomerate and consists of evenly distributed and well rounded rock fragments up to eight inches in diameter but averaging about one to one half inches, set in a brownish-grey matrix which has the appearance of a highly contaminated and biotitized porphyry (plate XV). Porphyry fragments predominate.

At two locations near the north end of Breccia ridge the breccia is cut by vertical quartz diorite porphyry dykes (see map 2). One of these is about 25 feet wide and follows along part of the contact of the Washington breccia with the Murray breccia. Near the center of the ridge there is a cream coloured porphyry mass containing round masses of porphyry
which are approximately one foot in diameter and are similar in composition to the rest of the mass but possess breadcrust structure. The attitude of this porphyry mass is unknown but it appears to be flat-lying. Small veins of magnetite-rich breccia also traverse the Murray breccia in its northeast and northwest peripheral regions.

Large inclusions of Upper Cretaceous sediments in the outer portions of the breccia have been observed. One is twenty feet in diameter and is composed of rounded pebble conglomerate. It is near the north end of the ridge on the west side. Near to it are what appear to be lenses of argillite. At the north end of the ridge there are several inclusions of argillite averaging about three feet in diameter. A foundered block of sandstone and argillite 200 feet in diameter which dips 55° west, appears to project into the breccia from the southeast wall. It is cut by a pebbly breccia sill which is approximately one foot wide. The argillite of this block is slightly foliated where it is in contact with the breccia.

At the north end of the ridge where the breccia is in sharp vertical contact with biotitized porphyry the latter is closely jointed parallel to the contact. Within the first fifteen feet adjacent to the contact, the breccia itself changes gradationally from a rock with irregular shaped inclusions of argillite and sub-rounded porphyry fragments set in a matrix which has the appearance of biotitized contaminated porphyry, to a similar rock containing a larger proportion of inclusions and more fully rounded fragments.
This change in the character of the breccia clearly indicates that it cross-cuts the porphyry.

The outer east side of a ledge about thirty feet wide on the east edge of Breccia ridge is composed of magnetite-bearing Washington breccia. The west side of the same ledge is composed of Murray breccia containing only a few veins of magnetite-bearing breccia. Both rocks are sheared or closely jointed parallel to their mutual contact which dips steeply to the west. Between the two breccias is a complex zone about ten feet wide consisting of numerous dark and light veins of porphyry, and veins of magnetite-bearing breccia, all of which are cutting Murray breccia.

Several widely spaced fractures trending across the length of Breccia ridge appear to have broken the Murray breccia into blocks which have moved vertically relative to one another.

A system of joints very similar to those on the summit of Constitution Hill, breaks the breccia at some localities into nearly equant blocks (plate XVI).

The exposures of breccia in the Glacier creek area are similar in appearance and composition to some of the Murray breccia of Breccia ridge. The lower contact of the lowest zone of breccia appears to dip 35° S. Although there is an abrupt change at the contact from the underlying grey-green hornblende quartz plagioclase porphyry to similar coloured breccia containing angular or rounded porphyry, quartzite, argillite, and andesite(?) fragments, the matrix of one is similar in appearance to the matrix of the other as seen in
Plate XVI - Shrinkage(?) joints in the Murray breccia on Breccia ridge.

Plate XVII - Shrinkage(?) joints in the quartz diorite porphyry on the summit of Constitution Hill.
the outcrop. Also, there is no surface of parting or abrupt discontinuity between the two rocks.

Microscopic Description. Despite their wide variations in megascopic appearance, the microscopic structures of the various Murray breccias are almost identical. On Breccia ridge most of them are highly biotitized, but the less altered specimens studied are described here.

In thin section the rock is observed to contain rounded or angular fragments of porphyry, sandstone, siltstone, and shale, in that order of abundance. Fragments of Triassic volcanic rocks are present, but are very rare. The fragments average approximately one and one half inches in diameter. In some specimens the matrix appears to be somewhat comminuted sub-cataclastic porphyry (p.45). However, because it is generally highly biotitized (p.77) its characteristics, other than those indicative of its cataclastic nature, are rather obscure. The matrix consists mainly of angular rock and plagioclase crystal fragments, some quartz crystal fragments, and in most cases, a few ragged shreds of poikilitic hornblende. There is a complete gradation in size from the largest fragments to extremely fine grained material (plates XVIII, XIX, XX, and XXI).

The majority of the larger fragments are quartz diorite porphyry. Most such fragments have an aphanitic matrix. Porphyry fragments with quartz in their matrixes only, are more common than those with quartz phenocrysts. In some of these fragments trachitic structure is exhibited by the sub parallel arrangement of plagioclase. One fragment contains
Plate XVIII - Photomicrograph of Murray-type breccia from Glacier creek, (plain light, x16)

Plate XIX - Same as plate XVIII but taken with crossed nicols.
a crystal of plagioclase at its margin which is only slightly rounded where it projects into the matrix (plates XX and XXI). Many of the smaller porphyry fragments are composed of single plagioclase crystals with small amounts of porphyry matrix adhering to them. Other small fragments consist of porphyry matrix only.

Plagioclase (An$_{26-52}$) in the porphyry fragments shows oscillatory zoning. One crystal studied under the microscope exhibits approximately nine distinct concentric zones, all of which are of the same order of size. The outer zones, one to five exhibit normal type zoning and their ranges are approximately An$_{26-52}$, An$_{38-52}$, An$_{34-52}$, An$_{44-52}$ and An$_{48-52}$ respectively. Zone six is zoned reversely with a range of only about An$_{52-50}$. Zones seven, eight, and core zone nine are not distinctly zoned, but together they form a discontinuous zone of the reverse type whose three portions are composed of approximately An$_{51}$, An$_{46}$ and An$_{38}$ respectively. There are unconformities between zones two and three, five and six, and possibly also between zones seven and eight and zones eight and nine.

The comminuted matrix of the breccias generally constitutes approximately 50% of the rock. Its components show evidence of swirling and much of it is streamlined around the larger fragments (plate XX). Besides plagioclase, quartz, and hornblende, there is considerable biotite, epidote, sericite and chlorite. Hematite, magnetite, pyrite, and sphene are also present.

An oscillatory-zoned plagioclase crystal (An$_{35-52}$) from
Plate XX - Photomicrograph of Murray breccia from Breccia ridge showing plagioclase crystal of porphyry fragment projecting into comminuted matrix, (plain light, x16)

Plate XXI - As plate XX only taken with crossed nicols.
the matrix of the breccia contains four distinct zones of similar size. Only the outer No.1 zone shows reverse zoning. The third zone contains many smaller zones within it. Zones one, two, three, and four have ranges of approximately $\text{An}_{43-38}$, $\text{An}_{35-40}$, $\text{An}_{36-52}$, and $\text{An}_{46-50}$ respectively. There is a sharp unconformity between zones one and two.

Another plagioclase crystal in the matrix is fairly smoothly zoned in a normal manner and its range is about $\text{An}_{28-65}$.

3. Washington Breccia

Field Occurrence and Description. Washington breccia outcrops along the east side of Breccia ridge for a length of about 1200 feet (maps 1 and 2). On its west side it is in fairly sharp and near vertical contact with Murray breccia in at least one locality (see p.60). To the east its contacts with the brecciated rocks of the border of the stock are indistinct and may be gradational. To the south its limits are fairly closely established.

The best exposure of Washington breccia is a pipe-like body approximately 250 feet high at the northeast end of Breccia ridge (plate XXII). Widely spaced horizontal joints are common in this mass. On its north edge it contains closely spaced vertical sheet-joints trending ENE probably parallel to its unexposed contact with the sediments and porphyries found immediately to the north. Another similar set of joints trends NNW parallel to those found along its west contact with the Murray breccia. Vertical sheet joints trending approximately E-W are present at the south edge of this pipe-
Plate XXII
Outcrop of part of the pipe-like mass of Washington breccia on the northeast edge of Breccia ridge. Looking southwest. Snow-covered talus and fractures.

Plate XXIII
Close-up of boulder of Washington breccia on talus slope shown in plate XXII. Strewn out fragments along bottom. Most fragments are slab shaped but some porphyry fragments are rounded.
like mass of Washington breccia.

The huge boulders and the cliff outcrops of the pipe-like mass are composed of slab-like and rounded fragments of light grey porphyry and bleached sediments (plate XXIII). In many instances the two types occur side by side. In general the angular slab-shaped fragments are bleached sediments whereas the porphyry fragments are equant, and are at least in part rounded. They are various sizes and are set in a dark bluish grey highly magnetic matrix containing finer angular particles of porphyry or sediment. The fragments probably average about three inches in diameter or length but one porphyry fragment three feet wide was observed in a talus boulder. Many spaces between many fragments are filled with green amphibole. Close packing of the slab-like and rounded fragments is common. Between assemblages of these close packed fragments, matrix material and smaller angular or rounded fragments are strewn out in parallel arrangement (plate XXIII). Most specimens of the breccia are fairly massive. Many contain chalcopyrite and malachite along fractures or on the edges of fragments.

Material similar to the matrixes of the Washington breccia but deficient in magnetite contains rare rounded porphyry fragments, and occurs on the north and south edges of the pipe-like mass. It is strewn out parallel to sheet joints which traverse it and which are similar to those nearby in the Washington breccia. There appears to be a fairly sharp but gradational contact between the Washington breccia and this finer material.
Microscopic Description. In the porphyry fragments the
plagioclase phenocrysts are of similar composition to those
of the normal porphyries. They are generally slightly altered
to epidote, kaolin(?), and calcite, in certain zones and
along irregular fractures and cleavage planes. Fine curved
stringers of hematite which join one another criss cross the
porphyry fragments. Hornblende crystals are completely
replaced by magnetite.

The angular bleached sediment fragments studied are ex-
tremely fine grained but a few scattered angular grains of
quartz are still visible (plate XXIV). These fragments
appear to be highly altered to clay minerals or pale chlorite.
Around their edges is a narrow halo of limonite which fades
out inward away from the magnetite-rich matrix of the breccia.

Magnetite clearly replaces the finer material of the
matrix and the fringes of the fragments. In some places the
matrix is almost completely replaced by magnetite. It may
also completely fill the intervening areas between close-
fitting, straight-edged fragments, or it may occur fringing
the fragments, with actinolitic hornblende in the cores of
the areas between the fragments. In some specimens the only
mineral in such inter-fragment areas is actinolitic horn-
blende.

Magnetite also occurs as small veinlets composed of
strings of interlocking globules. These veinlets may cross
an entire fragment or may wedge out part way through the
fragment. They possess halos of limonite which join with
those around the edges of the fragments.
Plate XXIV - Photomicrograph of Washington breccia. Angular bleached shale(?) fragments on right, porphyry fragment on left, black is magnetite, grey is actinolitic hornblende. Veinlet of calcite, chlorite, epidote, (plain light, x16)

Plate XXV - Silicified Washington(?) breccia from trenches SE of pipe-like outcrop shown in plate XXII. Faint silicified fragments in center, quartz vug upper right, (crossed nicols, x16)
In one section studied, a veinlet of chlorite, calcite, and epidote crosses the entire rock, and in so doing cuts across every other mineral or fragment in the rock (plate XXIV). Where it crosses the groundmass of a porphyry fragment it is composed of all three minerals, but where it crosses plagioclase crystals it contains only calcite and epidote. In bleached shale fragments it consists of calcite only, and small blobs of calcite occurring in the fragment near the veinlet gradually diminish in size and numbers away from it. Where it intersects actinolitic hornblende it is composed of chlorite only, and where actinolitic hornblende and magnetite occurring side by side are dissected by this veinlet it contains only chlorite and epidote. Although this veinlet cross-cuts every mineral in the rock, at one place it is cut off by a magnetite stringer. Narrower veinlets traversing the groundmass of the porphyries contain only chlorite.

In trenches to the south of the pipe-like mass extremely silicified and vuggy Washington (?) breccia is found (plate XXV).  

4. Fractured and Brecciated Rocks Along the West Contact of the Mt. Washington Stock.

From Glacier Lake north to a location about 700 feet east of the upper end of Pyrrhotite creek there is an irregular shaped zone consisting of discontinuous areas of highly fractured and brecciated porphyries, sediments, and volcanics. This zone is approximately 300 feet wide.

Along the west side of this zone on the fringes of the stock, there are numerous systems of net veinlets. The
Veinlets are about \( \frac{1}{8} \) inch wide and are composed of porphyry in volcanic rocks, or of actinolitic hornblende in the stock porphyry. Some xenoliths of country rock which appear to have been only slightly displaced from their original positions are found in the borders of the stock. Approximately 200 feet from the east side of the zone, the various rocks are highly fractured, but the blocks so formed are generally little disturbed. As a result, there are net veinlets of porphyry, actinolitic magnetic breccia with angular fragments averaging less than \( \frac{1}{8} \) inch in length, quartz and sericite, chlorite, sulphides, or combinations of these materials, criss-crossing the porphyries, sediments, and volcanics.

Further west along a line coinciding with the southward extension of Pyrrhotite creek there is a zone of finely brecciated, silicified, and mineralized rocks of various types.

F. Metamorphism and Alteration

1. General Statement

The only type of metamorphism dealt with in this thesis is the very limited contact or thermal metamorphism of rocks cut by the dioritic intrusions, or of inclusions in the intrusions or breccias. This metamorphism is caused by gases and heat of the intrusions and is expressed by chemical and mineralogical changes in the host rocks near the intrusive contacts. Its effects are difficult to distinguish from hydrothermal alteration.
The results of magmatic pressure—induration and foliation of the host rocks along intrusive contacts—have been described previously under headings C, D and E of this chapter.

Alterations considered for the most part to be deuteric, i.e. - plagioclase partially replaced by sericite or quartz, have been described previously (p. 41). Intense alterations of the rocks in areas which do not necessarily coincide with the zones of metamorphosed rocks along intrusive contacts are found in the Central arm-West arm area of Mt. Washington, an area of copper-gold mineralization. These alterations are described under the heading "Alteration". They involve considerable addition of new material as well as redistribution and recrystallization of original material in the altered rocks. The formation of pyrite and magnetite may be due in part to alteration but this section deals only with the common alterations which are generally considered to be of hydrothermal origin.

Although all the intense alterations occur in close proximity to the copper-bearing rocks of the West arm, silicification, and possibly sericitization, only, show close genetic relationships to copper-gold mineralization in the area.

2. Metamorphism

Thermal metamorphism is pronounced only in the immediate vicinity of the Mt. Washington stock, but even here distinct changes in the appearance of the intruded rocks are generally visible for less than ten feet. Dykes and sills emanating
from the stock appear to have had little effect on their host rocks. However, most of the Upper Cretaceous sediments are indurated and this may have been partly caused by nearby intrusions. Conversion of sandstones to quartzites and of shales to argillites (p.34) may be due in part to thermal effects caused by the intrusions.

The finer grained sediments are more greatly affected by the intrusions than are the coarse-grained sediments. Thermal effects caused by the porphyry of the Summit are shown by the dark rims in the sandstones along their contacts with porphyry. The dark zone is generally less than five feet wide and is caused by the recrystallization of the argillaceous matrixes of the sandstones to biotite and chlorite. Shale, argillite, and siltstone fragments within the Murray breccia, and similar rocks at the periphery of the Murray breccia (plate XV), are darkened in a similar manner. In two localities especially, scattered detrital grains of feldspar and quartz, up to 1/8" in diameter, which were deposited in the original argillaceous sediment, are recrystallized to rounded clots or to single crystals. Other grains of the same minerals appear to be unaffected. One of these localities is on the west side of Breccia ridge (map 2) and the other is at the large block of Upper Cretaceous sediments which projects into the Murray breccia on the southwest side of the ridge. The matrixes of such rocks, as seen under the microscope, are largely composed of mosaics of finely interlocking grains of biotite and chlorite. Feldspathic sandstones overlying the argillaceous rocks at both localities are hardly affected by
the heat of the igneous rocks.

At the lower contacts of a sill in Ice creek and of the Main sill in the East saddle, the fine grained sandstones have been visibly bleached for a distance of only a few inches.

Sandstones and shales intruded by quartz diorite porphyry on the west side of Constitution Hill (plate VII) are noticeably bleached for a distance of only a few feet from the contact.

Magnetite selvedges are found in places along the contacts of dioritic dykes with Triassic volcanic rocks. In MacKay creek the volcanic rocks contain up to 20% magnetite over a width of about fifteen feet adjacent to the slightly chilled border of the stock.

An outcrop possibly representing a block of matamorphosed Triassic volcanic material occurs about 600 feet NNW of Glacier Lake. It is composed of actinolitic hornblende (Z^C = 16°; pleochroism-X = medium pale brown, Y - medium brown green, Z = deep green; absorption- Z > Y > X), clear plagioclase (about An_{40}), and some apatite(?). The hornblende has been partially replaced by pyrrhotite, magnetite, and chalcopyrite.

The replacement of the fringes of plagioclase phenocrysts by fine interlocking recrystallized(?) grains of quartz and unzoned plagioclase of the groundmasses in some porphyries near the stock may be due in part to the thermal effects of the quartz diorite stock.

3. Alteration

Silicification. Silicification, like sulphide mineral-
ization, occurs most commonly in the vicinity of fractured rocks. There appear to be two major overlapping "zones" of rocks showing various degrees of silicification. The first zone includes the Central arm and the inner and central portions of the West arm excluding Breccia ridge. It coincides approximately with the position, or former position (now occupied by intrusive rocks or breccias) of the Triassic-Upper Cretaceous unconformity. The second zone coincides with Pyrrhotite creek and extends south of it to the south of No.1 fault. In both zones most of the rocks are fractured or brecciated.

Within these zones and on the West arm there are several flat-lying sheet-like or irregular-shaped bodies of white quartz containing some sulphides. They are a few inches to several feet wide. There are also some steeply dipping quartz veins. The rocks enclosing such veins or bodies of quartz are highly silicified, especially near their contacts with the quartz.

Net veins of quartz averaging about 1/4" wide traverse rocks of all types along the borders of the stock. Silicified Washington (?) breccia is found on the West arm (plate XXV). On the Central arm cherty silicified argillites, and silicified sandstones (p.36) are common near the unconformity, and similar rocks are found at various locations on the West arm.

Most of the sheared and brecciated rocks in fault zones of the Mt. Washington area are silicified.

The source of the silica in the altered zones presents
no problem. Some was likely locally redistributed from siliceous sediments. Much appears to have emanated from the Mt. Washington stock.

**Sericitization.** In most cases, sericitization is closely related to silicification. Sericite (muscovite) is nearly always present in noticeable quantities in net-veinlets of quartz and also as clear white flakes up to 1" in diameter scattered throughout quartz in fault zones and in the larger veins and irregular quartz bodies containing sulphides.

Intense sericitization occurs in a "sub-cataclastic" porphyry from a drill hole collared a few hundred feet east of No.1 saddle. The plagioclase and matrixes of the porphyries of this region are partly replaced by fairly coarse shreds of sericite.

**Biotitization.** The rocks of Breccia ridge and its immediate vicinity, excluding the zone of breccia and silicified rocks along its eastern edge, are intensely biotitized.

Much of the finely comminuted matrix of the Murray breccia is flooded with fine flakes of biotite. The argillaceous matrixes and less stable minerals in the fragments of Upper Cretaceous sediments are replaced in a similar manner. Some porphyry fragments in the Murray breccia, and all outcrops of porphyry in the vicinity of the breccia are brown due to partial biotitization. In these rocks biotite completely replaces hornblende crystals and certain zones or the cores of plagioclase phenocrysts (plate XXVI). It also occurs as veinlets or replacements of finer grains of hornblende in the porphyry groundmasses. Chlorite alteration is present in
considerable quantity in the less intensely biotitized rocks.

**Chloritization.** Chloritization is the most widespread alteration. However, it does not appear to occur with nearly the same degrees of local intensity as do the other alterations. Also, it seems to be supplanted by other alterations in their zones of intensity.

Most of the hornblende in the dioritic intrusions is partially chloritized. Some porphyry fragments in the biotitized Murray breccia exhibit pseudomorphs of chlorite after hornblende (plate XXVII).

Recrystallized matrixes of the Upper Cretaceous sediments contain much chlorite. This is almost certainly derived from primary material in the sediment.

**Argillization.** A zone of extreme argillic alteration of porphyry was uncovered by bulldozing in No.1 saddle. At two other locations, similar but much less intense alteration was observed. One locality is in the upper parts of Pyrrhotite creek and the other is 3000 feet west of No.1 saddle. All three occurrences are within fault zones.

In No.1 saddle the zone is exposed over an area of approximately 100 feet EW by 20 feet NS. The contacts of this zone with unaltered rocks are not exposed but outcrops of contaminated and biotitized porphyry occur about thirty feet to the south, and outcrops of only slightly biotitized porphyry occur about 100 feet to the north. Some of the altered rock in the bulldozer cut has been reduced to a crumbly, milky-white mass. No ferromagnesian minerals are preserved but the odd small grey quartz grain or quartz-sericite veinlet, or chocolate brown patch of iron oxide, are present. At
Plate XXVI - Photomicrograph of biotitized Murray breccia. Matrixes of sandstone fragments (lower right and lower center), matrix of the breccia, and cores of plagioclase phenocrysts in porphyry fragments are replaced by biotite. (plain light, x16)

Plate XXVII - Photomicrograph of Murray breccia showing pseudomorph of chlorite after hornblende in a porphyry fragment. Small crystals are sphene. (plain light, x16)
some locations where the rock is less highly altered its
dioritic appearance is clearly seen. Most of these rocks
possess sub-cataclastic structure.

G. Major Structures (see maps 1 and 2; cross sections 1 and 2)
1. General Statement

There are two major systems of structures in the Mt.
Washington-Constitution Hill area. Structures of the first
system are found throughout the area and coincide with the
regional NNW trend of the rocks. They owe their presence to
large scale orogenic movements. The second system is found in
the vicinity of Mt. Washington and owes its origin to more
local forces caused at least in part by the intrusion of
dioritic magma.

Extensive fracturing was accompanied by the intrusion of
porphyry at many localities near the Mt. Washington stock.
Also, many previously existing fractures were likely react-
ivated by the intrusion of the stock. For these reasons
structural interpretation at many places in the vicinity of
the stock is very difficult.

On aerial photographs, many structures within the Triassic
volcanic rocks are indistinct because of the similar appear-
ance and massive nature of these rocks. For identification
in them of all but the major faults, direct observation in the
field is necessary. Structures within the gently dipping
layered Upper Cretaceous sediments are more clearly observed,
both in the field and on aerial photographs.
2. Folds

The rocks of the Mt. Washington-Constition Hill area are on the eastward dipping limb of the Pacific Coast downfold (Clapp, 1917, p. 23) which occupies Georgia Strait. This is shown by the attitudes of the Upper Cretaceous sediments and of the Upper Cretaceous-Triassic unconformity (see cross section 2, and map 2—esp. East arm).

The configuration of the Upper Cretaceous-Triassic unconformity and of the layered Upper Cretaceous sediments at Mt. Washington indicates that the rocks in the vicinity of the stock are structurally elevated, and that they are elevated to their maximum height of several hundred feet directly over the center of the stock near MacKay Lake (cross section 2). Attitudes of the Upper Cretaceous rocks at various localities show that tilting and flexing, combined with faulting, have produced a complex domed structure. This dome flattens outward towards the outer fringes of Mt. Washington where the Upper Cretaceous rocks are nearly flat-lying.

At the west end of the East arm the sediments are folded downward in a monoclinal(?) fashion (plate IV).

3. Faults or Fractures

On the basis of field observations and aerial photograph studies, the writer believes that the rocks near the west and center of the mountain are cut by numerous fractures of all orientations, but many of which belong to two steeply-dipping sets, most of whose vertical components of displacement are less than fifty feet. The members of one of these sets generally tend to converge towards MacKay Lake whereas members
of the other set follow a N-S direction. Throughout this entire area of the mountain former fractures belonging to the two sets appear to be now occupied by porphyry dykes.

Larger scale fractures than most of those described above form a radial pattern about the Mt. Washington stock. Two such fractures, No.1 and No.2 faults, are known to be present, and one other, No.3 fault, almost certainly exists. Another known fault, No.4 fault, may belong to the radial pattern. It is probable that several other large radial fractures are also present, but because they are not within the Upper Cretaceous rocks their presence is not obvious. On the basis of aerial photograph interpretation, Veerman has distinguished two such faults in the Triassic rocks north of the stock.¹ The large radial fractures are as follows:

No.1 fault—a vertically dipping fracture running approximately E-W through No.1 saddle. The distribution of Upper Cretaceous sediments on either side of it shows that displacement on it is very small. However, argillite abutting porphyry can be seen approximately 3000 feet west of No.1 saddle (map 2). In places this "fault" appears to have been a gaping fracture now occupied in many places by sub-cataclastic porphyry, some of which is sheared, mineralized, brecciated, and altered.

No.2 fault—a vertically dipping fault running approximately NW-SE along the north end of the West arm. This fault is clearly seen as a lineament on aerial photographs. It, or a

lineament parallel to it and more than 1000 feet to the north-east of it, can be traced for more than twenty miles to the southeast, and possibly a few miles to the northwest of Mt. Washington. The vertical component of displacement on it is at least 100 feet and is likely much greater than 100 feet, for it completely cuts off the Upper Cretaceous sediments and the porphyry bodies within them to the south of it on the West arm, and possibly also on the East arm.

No. 3 "fault"—a steeply dipping fracture whose presence is not proven but which may trend SSW along Glacier creek, pass just north of the Summit, and continue to the SSW of the Summit where it may die out within Upper Cretaceous sediments or the Main sill. Shearing, fracturing, and brecciation of rocks along Glacier creek, and possibly some of the prismatic jointing in the vicinity of the Summit may be due to movements on this "fault". The positions of the Upper Cretaceous rocks on either side of the proposed fault indicate that little vertical displacement has occurred on it.

No. 4 fault— a fault in the Triassic basement which extends upward into the Upper Cretaceous sediments thereby producing the displacements and flexures in these rocks within the East saddle. Flexing may have occurred in a somewhat similar fashion to that described by Buckham (fig. 4). This fault trends approximately N-S. A vertical component of displacement in the order of 400 feet is indicated by the downward displacement of Upper Cretaceous rocks along it (map 2). It may trend north past the north end of the Central arm to the eastern fringes of the Mt. Washington stock. In the Triassic
rocks to the south of Mt. Washington it is not distinct but may possibly continue for several miles.

A positively identified fault—No.5 fault—follows along Pyrrhotite creek and appears to extend south along the east side of Breccia ridge. It becomes indistinct a few hundred feet northwest of the Summit and also in the Triassic rocks north of No.2 fault. However, a distinct linear feature in the Triassic rocks south of the mountain may represent its southward continuation. Movement on No.5 fault has disturbed and brecciated rocks for some distance on either side of it. Shearing in a few places indicate that this fault probably dips moderately or steeply to the east. Because it is crossed by several other fractures, three of which are No.'s 1, 2, and 3 faults, and because these fractures appear to have formed, or to have been reactivated, when it was formed, movement on it is complicated. Between No.1 and No.2 faults at the north end of Pyrrhotite creek the east side has been elevated at least 100 feet, but complex fracturing of the rocks in this area makes displacement determinations difficult. As is shown on cross section 1, the sediments to the west of No.5 fault near the headwaters of Pyrrhotite creek are at lower elevations than those to the east. This is partly due to movement on No.5 fault, but is also believed to be due in part to flexing of the sediments. Fracturing and intrusion of porphyry in the area extending south of Pyrrhotite creek to No.1 fault make displacement determinations almost impossible. Between No.1 and No.3 faults the distribution of Upper Cretaceous and brecciated rocks may
indicate that the main movement on the fault in this area was dilational.

The Upper Cretaceous-Triassic unconformity appears to have been a surface along which thrusting occurred. Shearing of the rocks along it or near to it, including some cross-cutting intrusions on the West arm, has been partly described previously (p.29). Within the outer part of the stock and at approximately 4400 feet in elevation in Glacier creek there is a nearly flat-lying zone of sheared and gouged material. This porphyry may have been caught up during the thrusting aside of Upper Cretaceous rocks by the stock. In many cases former flat-lying fractures are now occupied by quartz veins or porphyry.

Flat-lying tension joints are well developed at many localities and in all rock types of the West arm-Summit-Central arm area.

One NNW-trending, steeply-dipping fault on which the west side has moved upward relative to the east side, is known to exist at Ice creek (cross section 2). The writer believes that several similar faults are present in the area between Constitution Hill and Mt. Washington. Another steeply-dipping fault strikes ENE along Ice creek. Both faults exhibit shearing, introduction of calcite, and silicification. If projected eastward, the second fault would cut Constitution Hill near the west end of Wolfe Lake at a position where the sill of porphyry exhibits a maximum development of prismatic jointing. It could fit the requirements of the possible fault mentioned previously (p.51) because the Upper Cretaceous
sediments are found to the southeast of it only, suggesting that the southeast side was displaced downward relative to the northwest side. If this fault is projected to Mt. Washington it might be considered an extension of No. 4 fault.

H. Mineral Deposits

I. General Extent and General Description

Copper-gold deposits of possible economic significance have been found in the West arm-Central arm area. They are mainly in Upper Cretaceous or intrusive rocks. Copper deposits have also been found in Triassic rocks of the lower Murex basin and copper mineralization is known to exist in Triassic rocks at some localities between Mt. Washington and Constitution Hill.

Quantitative chemical analyses for copper, zinc, and molybdenum were made in the university geochemical laboratories on the sediments from several eastward-draining streams and rivers of the Campbell River-Cumberland region. The sediments taken from streams of the Mt. Washington- Constitution Hill area generally possess a higher percentage of copper and higher copper to zinc ratios than do those taken from the streams draining regions southeast or northwest of the area. The sediments acquired from MacKay creek contain twelve parts per million of molybdenum whereas those of Murex creek contain less than one part per million of molybdenum. Furthermore, none of the sediment samples from any of the other streams contains more than one part per
million of molybdenum.

As a result of the chemical analyses alone it appears almost certain that the Mt. Washington-Constition Hill area is one of distinct and considerable copper mineralization. The molybdenum content is probably high only in the MacKay creek sediment because MacKay creek flows across the Mt. Washington stock with which molybdenum is closely associated.

Because they were deposited in two unlike environments, the mineral deposits in the upper West arm-Central arm region of Mt. Washington are mineralogically and physically somewhat different from those in the Murex basin.

Deposits on the West arm are described in greater detail than the other deposits of the area since they are the most complex, have been more fully studied by the writer, and are most pertinent to the following sections of this thesis.

2. West Arm-Central Arm Deposits:

Physical Forms and Tenors. A system of copper-gold bearing quartz veins and of irregular shaped bodies of quartz and minor sulphide replacements is present in rocks of various types along the inner central part of the West arm and on part of the Central arm. The system coincides approximately with the outer fringes of the stock and with the position of the Upper Cretaceous-Triassic unconformity. Most of the larger deposits of the system appear to be gently dipping, and the information from several drill holes indicates that some of the gently dipping quartz outcrops north of No.1 fault may form a partly eroded but otherwise continuous vein 250 feet
wide, 600 feet long, and seven to fifteen feet thick. On the assumption that there is such a vein it has been calculated that it assays an average of approximately 2% copper, less than 1 oz. Ag per ton, and a trace of gold. A zone in which several chalcopyrite-rich outcrops occur, and which includes this vein, or veins, is over 100 feet wide and follows No. 5 fault from Pyrrhotite creek to No. 1 fault where a rich area of copper mineralization is exposed.

Comb quartz and vugs within the quartz are very common in flat-lying deposits. In some zones of massive sulphides the minerals are layered parallel to the bedding of the enclosing sediments.

Scattered small deposits of mineralized breccia, sediments, and porphyry are found at elevations of 4400' to 4500' in a region which extends along the West arm south of No. 1 fault and continues part way along the Central arm (maps 1 and 2). No. 1 vein is a quartz vein which is in silicified Washington (?) breccia of this region. It consists of several parallel quartz lenses in a tabular zone which dips 30° NW and is approximately 100 feet long by three feet wide. Sampling shows it contains 0.42 oz. Au per ton, 0.34 oz. Ag per ton, 0.8% Cu, 0.5% Pb, 0.5% Zn, and 4.1% As.¹ No. 2 vein on the west side of the Central arm is a four inch wide quartz vein which assays 1.14 oz. Au per ton.² It begins within the

border of the stock where it dips 50°E, and can be followed discontinuously up the Central arm where it is in Upper Cretaceous sediments.

Closely spaced joint surfaces between fragments in crackled porphyries, sediments, and volcanics at some locations around the fringes of the stock or alongside faults, are coated with thin films of sulphides. Sulphides may also be disseminated throughout the fragments. However, at no locality has extensive copper mineralization of this type been found. In the crackled porphyries only the mafic minerals are highly impregnated with sulphides. Some net veinlets which contain sulphides are also found in these regions of crackled rock.

Disseminated pyrite, pyrrhotite, and chalcopyrite are found at some locations near faults. Many of the sheared and silicified fault surfaces contain sulphides.

Magnetite deposits in the Washington breccia have been described previously (p. 68). The iron content of this breccia probably averages less than 20%.

Ore Minerals, Textures, and Paragenesis. An exhaustive study of the sulphide-bearing rocks has not been made. However, several polished surfaces of select samples were investigated under the microscope by the writer, and the information so obtained has proven most useful to this thesis. Numerous textures have been observed in the samples but those indicative of brecciation and open space filling are most common. Textures depend on the sizes of the mineral grains, the shapes assumed by the grains, and the pattern in which
the grains make contact with one another in aggregates. As a result descriptions of them are included in the account of the occurrences of individual minerals.

The following minerals, nearly all of which are almost certainly hypogene, are arranged in their approximate order of abundance in the following list:

**Pyrrhotite**, \((\text{Fe}_{1-x}\text{S})\) - occurs in large quantities in all but the massive quartz veins, and is closely associated with chalcopyrite. In some samples the two minerals exhibit mutual boundary relationships but in most chalcopyrite replaces pyrrhotite. Parallel alternating layers of pyrrhotite and chalcopyrite (banded textures) are common. Disseminations and slip surface coatings of pyrrhotite in various rocks are also common near intrusions or faults (plate XXIX), and especially along No. 5 fault in Pyrrhotite creek. Pyrrhotite replaces hornblende in many of the porphyries and in one locality it replaces actinolitic hornblende of a metamorphosed volcanic fragment (p. 75).

**Pyrite**, \((\text{FeS}_2)\) - present in all sulphide-bearing rocks except a very few in which it is completely replaced by later formed minerals. It occurs in close association with chalcopyrite and is especially common in quartz veins and silicified and brecciated rocks (plate XXVIII).

**Magnetite**, \((\text{Fe}_3\text{O}_4)\) - small specks are present in many of the quartz veins and irregular bodies of quartz but it occurs in quantity only in the Washington breccia or in Triassic rocks at intrusive contacts.

**Chalcopyrite**, \((\text{CuFeS}_2)\) - is the only major copper-
bearing mineral. It fills spaces in brecciated pyrite-
arsonopyrite-quartz rocks (plate XXVIII) where it has been
observed coating one inch long quartz crystals. It also
occurs in alternate layers with pyrrhotite in banded "ores"
and is present in disseminations or veinlets throughout
various rocks near some of the intrusions or faults (plate
XXIX). It is also present in small amounts in fractures in
the Washington breccia.

**Arsenopyrite**, (FeAsS) - in abundance only in
brecciated ores (plate XXVII) or in quartz veins and
irregular shaped sulphide-bearing bodies of quartz.

**Molybdenite**, (MoS$_2$) - is found as slip surface coatings
in crackled rocks within or near the borders of the stock and
at the head of Pyrrhotite creek, and is also found as flakes
up to one inch wide intimately mixed with coarsely crystalline
quartz a few hundred feet north of No.1 saddle.

**Sphalerite**, (ZnS) - occurs in small quantities in No.1
and No.2 veins where it fills fractures within quartz-pyrite-
arsonopyrite rock, and as scattered minute blebs throughout
chalcopyrite in specimens from the mineralized region north
of No.1 fault. A specimen from No.1 vein exhibits emulsion-
exsolution texture of chalcopyrite in sphalerite (plate XXX).

**Galena**, (PbS) - small amounts of it are present in
No.1 and No.2 veins and in some other quartz veins and
irregular-shaped bodies of quartz where it fills spaces in
the fractured quartz. It may contain silver.

**Bornite**, (Cu$_5$FeS$_4$) - is not very common but is present
replacing pyrite and chalcopyrite in veins north of No.1
Plate XXVIII - Photomicrograph of a brecciated portion of No.1 quartz vein. Brecciated pyrite (mottled grey) and arsenopyrite (white, bottom center) are healed by quartz and other gangue (dark grey) and chalcopyrite (center to top. Dark patches caused by scour during polishing). Pyrite is slightly strewn out from left center to top center. (field length approx. 15 mm.)

Plate XXIX - Photomicrograph of disseminated pyrite (grey mottled crystals upper right), and chalcopyrite and pyrrhotite (not distinguishable from one another) in sandstone 1000 feet west of No.1 saddle. Chalcopyrite in veinlet (right, center). (field length approx. 15 mm.)
fault. It is replaced in turn by chalcocite and covellite. Some or all of it may be secondary.

\textbf{Tetrahedrite-Tennantite(?), } \text{(Cu,Fe,Zn,Ag)}_{12} \text{(As,Sb)}_{4} \text{S}_{13} \text{ - small grey blebs within pyrrhotite, chalcopyrite, or gangue in many of the polished sections studied are believed to be tetrahedrite-tennantite. They likely posses considerable silver for most assays show that at least some traces of silver are present in most of the veins.}

\textbf{Wehrlite, } \text{(Bi}_{3}\text{Te}_{2} \text{plus Ag and S), and Hessite, } \text{(Ag}_{2}\text{Te)} \text{ - present in a few small veinlets cutting "banded" chalcopyrite and pyrrhotite from a specimen taken from the mineralized region north of No.1 fault (plate XXXI).}

\textbf{Gold(?), } \text{(Au) - no native gold was identified in the samples studied but some is likely present in the veins. Pyrite and/or arsenopyrite are believed to be the main carriers of gold.}\textsuperscript{1}

Supergene minerals and/or alteration products of the previously listed minerals are fairly common. They are:

\textbf{Chalcocite, } \text{(Cu}_{2}\text{S)} \text{ - occurs fairly commonly as veinlets or irregular-shaped grains mainly in chalcopyrite and pyrite. Sooty chalcocite is also found in decomposed vein material. In some cases it has almost completely replaced pyrite so that only rounded residuals of this mineral remain. Some of it may be hypogene but much of it is supergene.}

\textbf{Covellite, } \text{(CuS)} \text{ - occurs as small blades in}

\textsuperscript{1} \text{personal communication with Gordon Murray, president of Mt. Washington Copper Company.}
chalcocite and bornite and as fracture fillings throughout the quartz veins.

Native Copper, (Cu) - found on oxidized vein material at some localities.

Malachite, (Cu$_2$(CO$_3$)$_2$(OH)$_2$) - has developed in small quantities only because of the deficiency of carbonate in the rocks of the mountain. It forms crusts on some of the vein material and is present on the surfaces of chalcopyrite-mineralized boulders of Washington breccia.

Molybdite(?), (Fe$_2$O$_3$·3MoO$_3$·8H$_2$O) - a yellow oxidation product of molybdenite which is likely molybdite but may be powellite is found with some of the molybdenite.

Realgar, (AsS) and/or Orpiment, (As$_2$S$_3$) - occur(s) as oxidation products in some arsenopyrite-bearing veins.

Paragenesis of the ore minerals appears to be similar in many respects to those of most hydrothermal ores as listed by Edwards (1954, p.136). More than one generation of pyrite may be present but pyrite is always an early mineral of the depositional sequence. The major gangue mineral quartz occurs in at least two generations but it was likely deposited throughout most of the period of mineralization and during more than one phase of brecciation.

The probable sequence of deposition of the most important metal-bearing minerals is listed below. The exact positions of molybdenite and bornite in the sequence are unknown. Bornite is post chalcopyrite and pre chalcocite but is tentatively placed in the fifth position. Those minerals listed together are at least in part contemporaneous,
Plate XXX - Photomicrograph of a specimen from No.1 vein showing emulsion-exsolution texture exhibited by sphalerite (medium grey) and chalcopyrite (white), and segregation veinlets of chalcopyrite. Dark areas, excepting the quartz grain in the lower right, are gouges formed during polishing. (field length approx. 0.5 mm.)

Plate XXXI - Photomicrograph of a mineralized specimen from a flat-lying quartz-sulphide body north of No.1 fault. Wehrlite veinlet (white) cuts across pyrrhotite and chalcopyrite (not distinguishable from one another in photograph). The veinlet contains patches of hessite (grey, low relief), and oriented inclusions of pyrrhotite (dark rims, high relief). (field length approx. 0.5 mm.)
or else their inter-relationships are unknown.

(1) Magnetite, Pyrite, Arsenopyrite
(2) Pyrrhotite
(3) Molybdenite - ?
(4) Chalcopyrite, Sphalerite, Tetrahedrite-tennantite(?), Galena
(5) Bornite - ?
(6) Wehrlite, Hessite, Gold(?)
(7) Chalcocite, Covellite

Genetic Classification. It is of interest to note that the mineral deposits in the vicinity of the Mt. Washington stock are similar in a great many respects to the porphyry copper deposits of southwest United States.

These mineral deposits were formed in a near-surface environment. Comb structures and vugs in the quartz veins are common indicating extensive open space filling. This is generally considered compatible only with a near surface environment. Evidences for this environment are also deduced from the nature of the intrusions and breccias, and probable thickness of overlying rocks during formation of the deposits (p.48).

High temperature minerals predominate within the deposits. Exsolution chalcopyrite in sphalerite indicates temperatures of above 350°-400°C during deposition of these minerals (Edwards, 1954, p.98). The deposits also contain tellurides (wehrlite and hessite) which are generally considered to be low temperature minerals. Temperatures during deposition of the vein minerals may have varied
Because they were formed for the most part at least, at high temperatures, and in a near-surface environment, most of the West arm-Central arm mineral deposits could be classified as Xenothermal deposits (Buddington, 1930, p.205).

**Structural Controls.** The distribution of the mineral deposits (see maps 1 and 2) suggests that many of them may have been localized by or near to the following structures:

(1) The Upper Cretaceous-Triassic unconformity. Dilational zones may have formed at or near to the unconformity. Impermeable layers in the Upper Cretaceous sediments above it may have halted the ascent of hydrothermal solutions.

(2) Large, steeply-dipping faults or fractures, and especially No.5 fault.

(3) The system of fractures smaller than those of part (2) which surrounds the stock. Flat-lying fractures of this system were especially important controls.

A combination of all three of the above major controls appears to be present in the heavily mineralized region extending south of Pyrrhotite creek to No.1 fault.

Bedding in the sediments determined the nature of many of the fractures formed and may have aided or hindered mineralization depending on its consistency, width, or attitude. Permeable sediments may have been mineralized to a greater degree than non permeable sediments.

3. Deposits of Murex Creek and Vicinity, and of Ice Creek

In Murex creek, outcrops of Triassic rocks occurring
over a length of several hundred feet and at elevations of about 2400 feet to 2700 feet are highly fractured and spottily mineralized with pyrrhotite and chalcopyrite. Many of the fractures strike at N50°E and dip 55°SE. A steeply-dipping porphyry dyke approximately 100 feet wide follows along the east side of the entire belt of mineralized rocks. Grade and economic possibilities of the sulphide mineralization in the belt were described previously (p. 4).

Slip surfaces on fragments of fractured volcanics at one locality about 2000 feet in elevation on the northeast end of the East arm are coated with thin films of pyrite and chalcopyrite.

Small deposits of arsenopyrite are present in the fault zones of Ice creek (p. 85). These have been described by Cunning (1930, p. 76A).
V STRUCTURAL DEVELOPMENT OF MT. WASHINGTON

The Puget orogeny of post-Upper Cretaceous times included folding and faulting along NNW-trending axes and affected strata as young as Miocene on Vancouver Island (White, 1959, p.96). Folding and faulting during this orogeny appear to have been largely responsible for elevating the Upper Cretaceous sediments at Mt. Washington from sea level or from below sea level to their present maximum heights of greater than 5000 feet (cross section 2).

At Mt. Washington the structural dome (p.81), the large radial faults (p.82), at least one transverse fracture—No.5 fault, and the system of smaller fractures surrounding the stock (p.81) were likely formed or reactivated by the forceful intrusion of the stock.

Cross section 1 indicates that the dome may have had a maximum structural relief of approximately 1000 feet directly above the stock. However, the relief was probably greater than 1000 feet since in the cross section the interpretation of the position of the eroded layer of sediments which was formerly over the stock has taken only flexing into account whereas extensive punching up of blocks of rock above the stock likely occurred. That such punching likely took place is shown by the elevated position of the northern part of the block of rocks enclosed by the western edge of the stock and No.'s 1, 2, and 3 faults.

When compared to the structural reliefs of many domes in the western United States which are known to be caused by the
intrusion of magma, the apparent structural relief of the dome at Mt. Washington is small. Because of this it might be concluded that doming by the stock could not have produced the larger fractures surrounding it. However, Wisser (1960), who has performed several scale model experiments on doming concludes (p. 11) that "The degree of doming capable of producing radial and concentric fractures is astoundingly small".

The role played by tectonic structures in determining the location of the Mt. Washington stock is unknown. It is also not known how much movement on faults of the area can be attributed to their reactivation by forcible intrusion. However, it is known that some large post-Late Cretaceous movements occurred both before or during, and after the intrusion of at least part of the dioritic magma. That it occurred before or during the intrusion of the Main sill is shown by the up-stepping of this sill at No. 4 fault in the East saddle (p. 49), and that it took place after intrusion of the stock is well demonstrated by the fact that the Mt. Washington dome which was formed by the intrusion of the stock is cut in half by No. 2 fault or by a parallel fault near to it.

Noble (1952) describes the forcible intrusion of a composite stock near the Homestake mine in South Dakota. This stock punched sections of the overlying rocks ahead of it such that horsts were formed between paired faults and that the overall structure formed was that of a dome. It is significant to note that the domed rocks described by Noble
are steeply dipping Precambrian schists and erosional remnants of nearly flat-lying Cambrian strata which overly the schists. He suggests that were it not for the presence of the Cambrian strata which are readily observed to be elevated, the doming and other evidences for forcible intrusion would be scarcely noticeable so that the significance of the parallel faults and porphyry bodies would almost certainly not be realized by geologists mapping the area. Rather, the geologists would explain the elevated area in the vicinity of the intrusions by differential erosion. A somewhat similar situation exists at Mt. Washington where massive and similar appearing Triassic volcanics whose attitudes are difficult to determine are overlain by nearly flat-lying outliers of Upper Cretaceous sediments and both have been forcibly intruded by the Mt. Washington stock.
VI ORIGIN OF THE PORPHYRY BODY AT CONSTITUTION HILL

Although the writer did not map Constitution Hill, several traverses were made in its vicinity. The porphyry intrusions at and near to the hill appear to be closely related in origin to the intrusions at Mt. Washington.

The porphyry body at Constitution Hill may have been intruded through a feeder underlying the hill so that the only relationship existing between it and the Mt. Washington stock may be that they likely emanated from the same chamber containing quartz diorite (p. 52). On the other hand the Constitution porphyry may represent the bulbous termination of a sill-like body (cross section 2) which originated at the Mt. Washington stock and formed in a manner similar to many of the sill terminations of the Pando region of Colorado (Tweto, 1951, p. 516). The body may have formed by a build-up of magma which had become increasingly cool and viscous and had been subjected to increasing lithostatic pressures due to the probable increase in the thickness of the sediments overlying it, as it moved eastward from the stock. After the intrusion of porphyry had ceased, the sediments between the feeder stock and Constitution Hill may have contained a continuous sheet-like sill or they may have contained only scattered lenses of porphyry. There are several facts which support this second mode of origin. They are:

(1) as is shown in cross section 2 the Upper Cretaceous sediments are in conformable contact with the lower part of the sill at localities on both the west and
east sides of Constitution Hill but have been observed to
dip 60°E 1000 feet east of the edge of the hill. These facts
may indicate that the porphyry body is part of a sill which
wedges out to the east.

(2) the only large magma feeder observed in the entire
area by the writer is the Mt. Washington stock, and a few
dykes are found in the Triassic rocks in the vicinity of the
feeder whereas no porphyry intrusions in Triassic rocks in
the immediate vicinity of Constitution Hill were observed.

(3) several thin erosional outliers or grabens of
Upper Cretaceous sediments lying on Triassic volcanic rocks
and containing sills may be present between Mt. Washington
and Constitution Hill. These sills may be remnants of the
former sheet-like body or lenses mentioned above. Two such
outliers containing remnants of sills are known to be present
approximately 2500 feet west of Constitution Hill. Other
outcrops of porphyry occurring in areas southeast of Mt.
Washington which are almost certainly underlain by Upper
Cretaceous sediments, have been observed by the writer.

(4) there is very little contact metamorphism of the
Upper Cretaceous sediments in the two outliers mentioned in
part (2), and at Constitution Hill where the sediments are
overlain by several hundred feet of porphyry, they are hardly
affected (p.75). The writer has also not observed any
intense hydrothermal alteration or copper mineralization at
these outliers or at Constitution Hill. These facts would
appear to indicate that the feeder for intrusion of the
porphyry was far removed from the Hill and outliers, or else
that it was very small and is now completely covered by porphyry, because in the vicinity of a known feeder – the Mt. Washington stock – the rocks have been highly indurated, altered, and in many localities, intensely mineralized.
A. Current Theories on the Origin of Breccia Pipes

The origin of breccia pipes has long been the subject of much controversy among geologists. However, it is generally agreed that genetic relationships exist between the intrusion of magma and the formation of most breccia pipes. Gates (1959, pp.806-812) has made an excellent summary of the current beliefs on the origin of breccia pipes.

Burbank (1941, p.177) explains the development of breccia pipes in the San Juan Mountains of Colorado as follows:

"The inferred history of pipe formation may be briefly summarized up to the point of complete development of the pipe,-----. The passage of magmatic emanations up through favourably jointed and fissured rock may have caused certain chemical or volume changes along some vertical axis of greatest concentration, which impaired the strength of the rock and induced local crackling and crumbling. The zone of disintegration spread outward from the axis along generally curved surfaces-----. As the breccia mass spread into the surrounding rock it tended to assume the form either of a ring zone or a cylindrical core. When the breccia core became partly displaced with intrusive rock,-----further external fracturing ensued as a result of upthrusting by the intrusive body."

In describing the breccia pipes near Bagdad, Arizona, Anderson, Scholz, and Strobell (1955, p.42) express the opinion that Burbank's proposed method of origin (above) is as good an explanation as can be offered and they further state:

"When gas pressure was unusually great, gas explosions probably carried fragments upward, and abraded them during transport. The possibility cannot be denied that subsidence may have occurred, particularly in the pipes that are largely
shattered host rock, but neither can it be denied that local upward movement has taken place, and rock fragments have been rounded by abrasion. Again a mass of breccia might have been uplifted bodily by the upward thrust of an underlying plug or domelike intrusive mass, accounting for some pipes containing fragments derived from rock units below."

B. Development of the Murray Breccia

The pipe-like shape of the Murray breccia may be inferred because it is in near vertical contact to the north with biotititized porphyry and to the east with close-jointed Washington breccia.

The Murray breccia was formed during part of the period of intrusion of porphyry at Mt. Washington. Its content of porphyry fragments and its cross-cutting relationship with biotititized porphyry of the Main sill indicate that it is younger than much of the porphyry, but because it is intruded by dykes of porphyry it was formed before the final stages of magmatic activity.

The intrusive nature of much of the breccia is apparent because some of it occurs as a sill in a foundered block of Upper Cretaceous sediments and because it contains numerous inclusions. Many of its characteristics such as swirled streaks of dioritic material, shrinkage(?) joints (plate XVI), and its dioritic composition are indicative of its igneous nature. These, and the presence of a little abraded plagioclase crystal projecting from a porphyry fragment into the matrix (plates XX and XXI) indicate that it was highly mobile when formed.

Rapid changes in the appearance and content of the breccia
may be the results of different conditions existing at various locations in the pipe or of vertical movements within the pipe of blocks of breccia bounded by the transverse fractures shown on map 2. Such movements of blocks may have been caused by changes in the magmatic pressure of the underlying stock. Its results could be that different appearing breccias formed at different levels in the pipe are now seen side by side, and because intermingling of these different appearing breccias may have occurred during movement of blocks gradations exist among them. Slumping or shattering of the Upper Cretaceous roof rocks during movement of the blocks may account for the local presence of rubbly Murray breccia.

The presence of well rounded fragments such as those of the Murray breccia has been recorded in descriptions of many breccia pipes. Rust (1936, p.58) reports that the diatreme breccias of southeastern Missouri are so similar in appearance to conglomerates that they were mapped as such in the early 1900's.

The majority of the fragments in the Murray breccia are porphyry whereas Triassic rock fragments are extremely rare. This may be due to the fact that most of the rock lying directly under the pipe when it formed was porphyry.

Layering is not uncommon in breccia pipes. Hunt (1958) has described layered breccia pipes of the La Sal Mountains in Utah whose breccias are strikingly similar to the Murray breccia. Layering in the Murray breccia may have developed by settling and subsequent segregation of mobile material which occurred during the subsidence of blocks within the pipe. Its irregular nature and contorted appearance may be
a reflection of many factors such as unequal rates and amounts of subsidence or the different manners in which the breccia was intruded at different locations within the pipe. The writer does not rule out the possibility that some of the layered Murray breccia may be pyroclastic material brought to its present position by subsidence.

After considering the possible origins of some of the features of the Murray breccia the writer has made the following conclusions regarding its formation:

(1) the breccia formed after the intrusion of much magma had occurred from the stock into the Upper Cretaceous sediments.

(2) the intruded magma may have sealed off the stock from the surface thereby forming a closed system in which gases and magma accumulated such as was thought by Rust (1936, p.70) to have occurred at the diatremes of Missouri.

(3) gaseous and magmatic pressure may have caused formation of vertical fractures above the stock which coincided with the present position of Breccia ridge.

(4) the breccia was formed by processes similar to those described by Burbank, and Anderson, Scholz, and Strobell (p.105). Much of it may have been intruded in a manner somewhat similar to the intrusion breccia at Kilkenney, Scotland (Pitcher and Read, 1952), and the intrusion breccias near Horseshoe Bay, British Columbia, some characteristics of which have been described to the writer by Ross.¹

¹ Dr. J.V. Ross, Assistant Professor, University of British Columbia
Its formation may have been accompanied by some vulcanism.

(5) intrusion of porphyry into the breccia occurred after its formation.

C. Development of the Washington Breccia

The Washington breccia assumes a pipe-like shape. It is almost certainly younger than the Murray breccia because veins of breccia which appear to be offshoots of it are present within the Murray breccia. It may have formed soon after the Murray breccia by bursting and upthrusting or slumping of brecciated rocks within a dilational fracture, the No.5 fault. Dilational movement may have occurred on the fault when the block of rocks bounded by No.'s 1, 3, and 5 faults foundered into the stock underlying it.

Bursting of close jointed rocks or of sediments which were easily split along their bedding planes may have contributed the high proportion of slab-like fragments to the breccia. Many of its rounded fragments may have been derived from the Murray breccia. Some rounding of fragments and the strewing out of matrix between assemblages of angular and partly rounded fragments and along the edges of the pipe-like outcrop may have been caused by gas streaming accompanied by fluidization, which is believed by Reynolds (1954) to be an important geological process.

Gates (1959, p.809) considers that rock bursting, "perhaps deserves more consideration than has been granted it heretofore." He believes that a study of rock bursting within mines could help to reveal the origin of breccia
pipes. Concerning rock bursting in mines he states (p.810, 811, 812):

"Large bodies of rock may be completely brecciated with relatively little movement of the body as a whole. Rock bursts can produce a variety of breccias. Some are incoherent masses of angular fragments of all sizes ranging from dust to blocks weighing tons. In a volcanic area, especially where the rocks are brittle and siliceous, rock bursting might occur if free faces were formed."

Actinolitic hornblende in the Washington breccia may have been deposited by volatile-rich solutions which emanated from the underlying stock. Magnetite in the matrix may have been derived from the stock by a process similar to that described by Mackin (1948) for the magnetite deposits at Iron Springs, Utah. However, the nature of the veinlet of calcite, epidote, and chlorite described previously (p.71) may indicate that much of the magnetite was derived from the brecciated rocks by a process involving secretion.

D. Development and Significance of the Fractured and Brecciated Rocks:

Forcible intrusion of the Mt. Washington stock accompanied by explosive activity caused by expansion of gases accumulating above and within the stock may have caused the formation of the zone of fractured and brecciated rocks along the west border of the stock.

The significance of these rocks, and to a lesser extent of the other breccias, is that they are found only in the vicinity of the Upper Cretaceous-Triassic unconformity. This may indicate that vertical and lateral development of the stock was restricted within the Triassic rocks because of
their massive nature, but that when the stock had reached near to the unconformity it breached the surface of the Triassic rocks thereby causing extensive brecciation in its vicinity. It may then have spread out laterally within the Upper Cretaceous sediments to form the Main sill and the porphyry body at Constitution Hill. This method of intrusion is so similar to that proposed by Gunning (1932) for the Nimpkish "batholith" of north-central Vancouver Island that the latter must be considered in this section. Concerning the intrusion of the Nimpkish "batholith" Gunning states (p.303):

"-----the limestone intruded by granodiorite-----is underlain by a massive assemblage of flows and volcanic fragmentals, at least several thousand feet thick, known as the Karmutsen volcanics. These rocks form a hard, competent member. The limestone is about 1000 feet thick and above it is a thickness of about 400 feet of argillite, impure limestone, quartzite and tuff. This succession, and the subsurface form of the granodiorite as well as the close folds in the limestone,-----suggest the following method of intrusion. The magma-----arose along a north-westerly trending line of weakness. It ascended through the competent Karmutsen volcanics in rather restricted form but under great pressure. Except in so far as stoping was operative at this stage, the magma found great difficulty in enlarging its chamber. But when the intrusive had pierced through the volcanics it encountered the less competent limestone and argillites which would yield more readily to compressive forces than the underlying volcanics. Once in the limestone the magma was able to enlarge its chamber by lateral extension. It overrode the underlying volcanics, pushing back the limestone into a series of more or less tightly compressed folds-----"
The geological history of the Mt. Washington area during the following eras, periods, and epochs may have included the following events:

(1) Triassic: - deposition on the ocean bottom of great thicknesses of andesitic and basaltic volcanic rocks.

(2) Late Jurassic-Early Cretaceous-Late Cretaceous: - elevation to above sea level of the Triassic rocks accompanied by their erosion and followed by their depression to below sea level during the formation of the Pacific coast downfold.

(3) Late Cretaceous: - deposition of several thousand feet of sediments including shales, sandstones, conglomerates and coal beds, under conditions described by Mackenzie (1922).

(4) Cenozoic: - accentuation of the Pacific coast downfold by folding and faulting along NNW axes. The inland areas were elevated to above sea level and much of the Upper Cretaceous sediments were eroded. During early Oligocene(?) dioritic magma was intruded into the rocks of Mt. Washington and Constitution Hill. The intrusion of the Mt. Washington stock caused the formation of the domed structure in the rocks of the mountain, the radial fracture pattern, and the breccias, and was followed closely by the deposition of metallic minerals. Later faulting cut the domed structure in half. Erosion of much of the fractured rock at Mt. Washington initiated the formation of the MacKay and Murex basins. At the same time, erosion of the cover of sediments...
at Constitution Hill likely occurred so that the porphyry body at the hill was exposed to the surface.

(5) Pleistocene: - modification of the topography during two stages of glaciation (Clapp, 1917, p.350). During the climaxes of the glacial stages the ice on Vancouver Island was highest at an ice divide at Buttle Lake (fig.1), and its surface sloped downward towards the east. Mathews has found evidence that the ice reached a maximum elevation of 6300 feet on Mt. Albert Edward, which is between Buttle Lake and Mt. Washington. Therefore the ice was likely never much higher than the Summit which is at an elevation of 5215 feet. As a result erosional features of the first three phases of glaciation proposed by Davis and Mathews (1944, p.409) were formed at Mt. Washington during the advance and retreat of the ice. Such features are the Summit which is domed, the rounded arms, and the U-shaped MacKay and Murex basins which the ice accentuated.

In the Strait of Georgia and on the Coastal plain the ice was much thicker than it was at Mt. Washington. It smoothed prominences such as Constitution Hill as it moved southeast.

(6) Recent: - little erosion, mainly the formation of small but steep-walled river or stream valleys in soft glacial material or along zones of fractured rock.

1 Dr. W.H. Mathews, Associate Professor, University of British Columbia
2 Personal communication with W.H. Mathews.
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