GEOLOGY OF THE SOUTHEASTERN PART OF THE SULTAN QUADRANGLE KING COUNTY, WASHINGTON

by

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INTRODUCTION

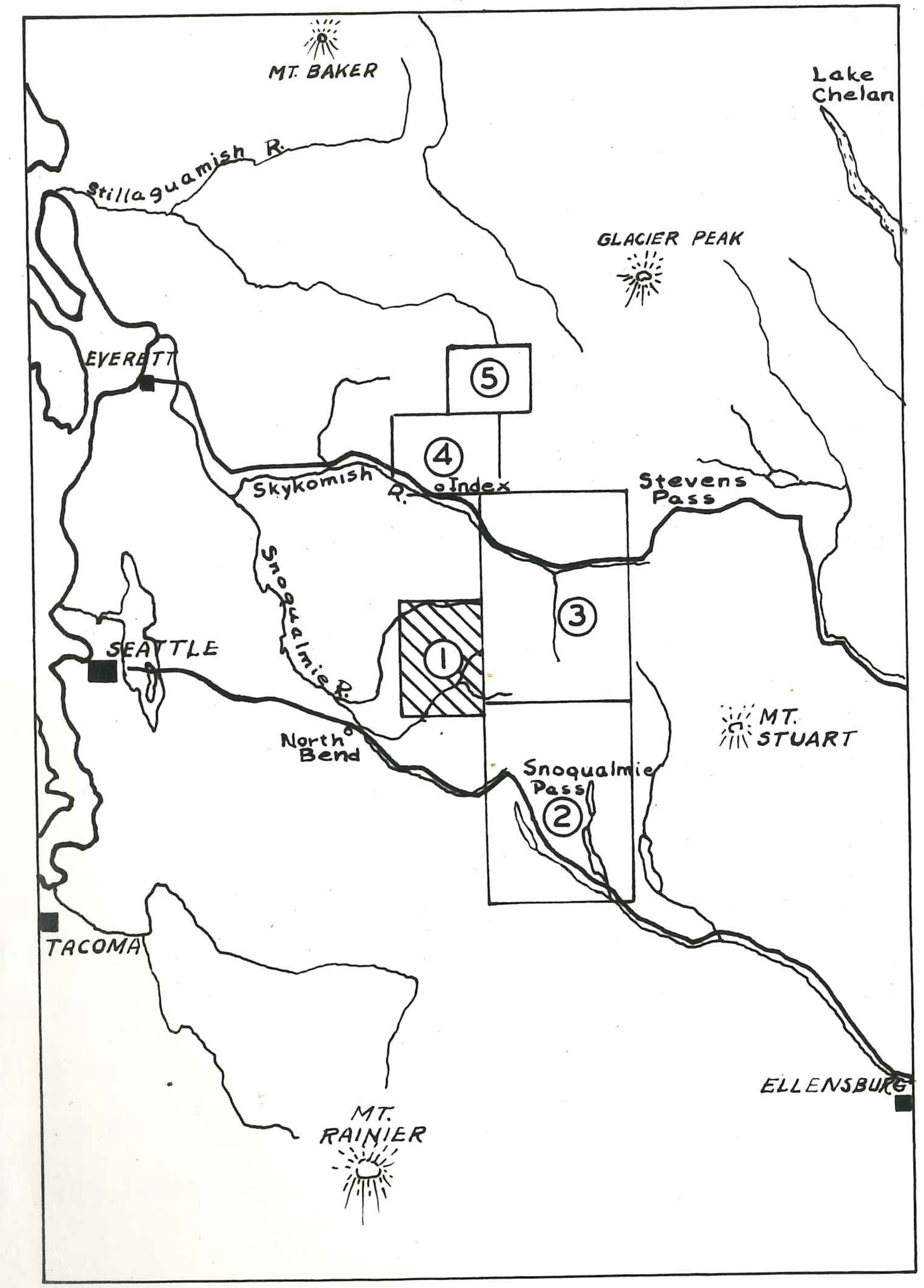
Location

The area included in this investigation is situated about forty miles east of Seattle, within the Cascade Mountains (cf Plate 1). It includes about 135 square miles in the vicinity of the North and Middle Forks of the Snoqualmie River. The town closest to the area is the small municipality of North Bend, which is located on the main cross-state highway from Seattle to Yakima by way of Snoqualmie Pass. From North Bend gravel roads extend up both the North and Middle Forks of the Snoqualmie River for about twenty miles and allow limited access to the area. Most of the region outside of these main river valleys is accessible only by trail.

Purpose of the Investigation

For many years intermittent prospecting has been carried on in the vicinity of the North and Middle Forks of the Snoqualmie River. The southeastern part of the Sultan

PLATE 1



VICINITY MAP

① Area included in this thesis
② U.S.G.S. Snoqualmie Folio (9)
③ Smith, W. S., Skykomish Basin (11)
④ Weaver, C. E., Index District (15)
⑤ Spurr, J. E., Monte Cristo District (12)

quadrangle includes some of these deposits which have been actively prospected in recent years. No written description of the general geology or mineral deposits of this area was available, and the only geological information consisted of the State of Washington preliminary geological map of 1936 (1). This map was based on the information available at the time it was prepared and showed the Snoqualmie granodiorite as occupying much of the area.

No visitor to this region could help but be impressed by the variety of granitic rock types present. The purpose of this investigation has been two-fold: first, to map the general geology of the area, with particular emphasis on fixing the boundaries as closely as possible of the various types of granitic rocks; and, second, to map and describe the mineral deposits and correlate them with the areal geology. As the study progressed it became apparent that the area offered some interesting relationships between the sedimentary and volcanic rocks and between some of the granitic rock types, and these relationships have been discussed in some detail from both a descriptive and genetic standpoint.

Field Work

The writer had made an occasional trip into this area to visit some of the mineral deposits prior to commencing work on this thesis in 1949. During the summers of 1949 and 1950 a total of five months were devoted to field work in this area.

During the past two years approximately 250 thin sections of rock and ore specimens collected in the field have been made by the writer in the University of Washington laboratory.

GEOGRAPHY AND PHYSIOGRAPHY

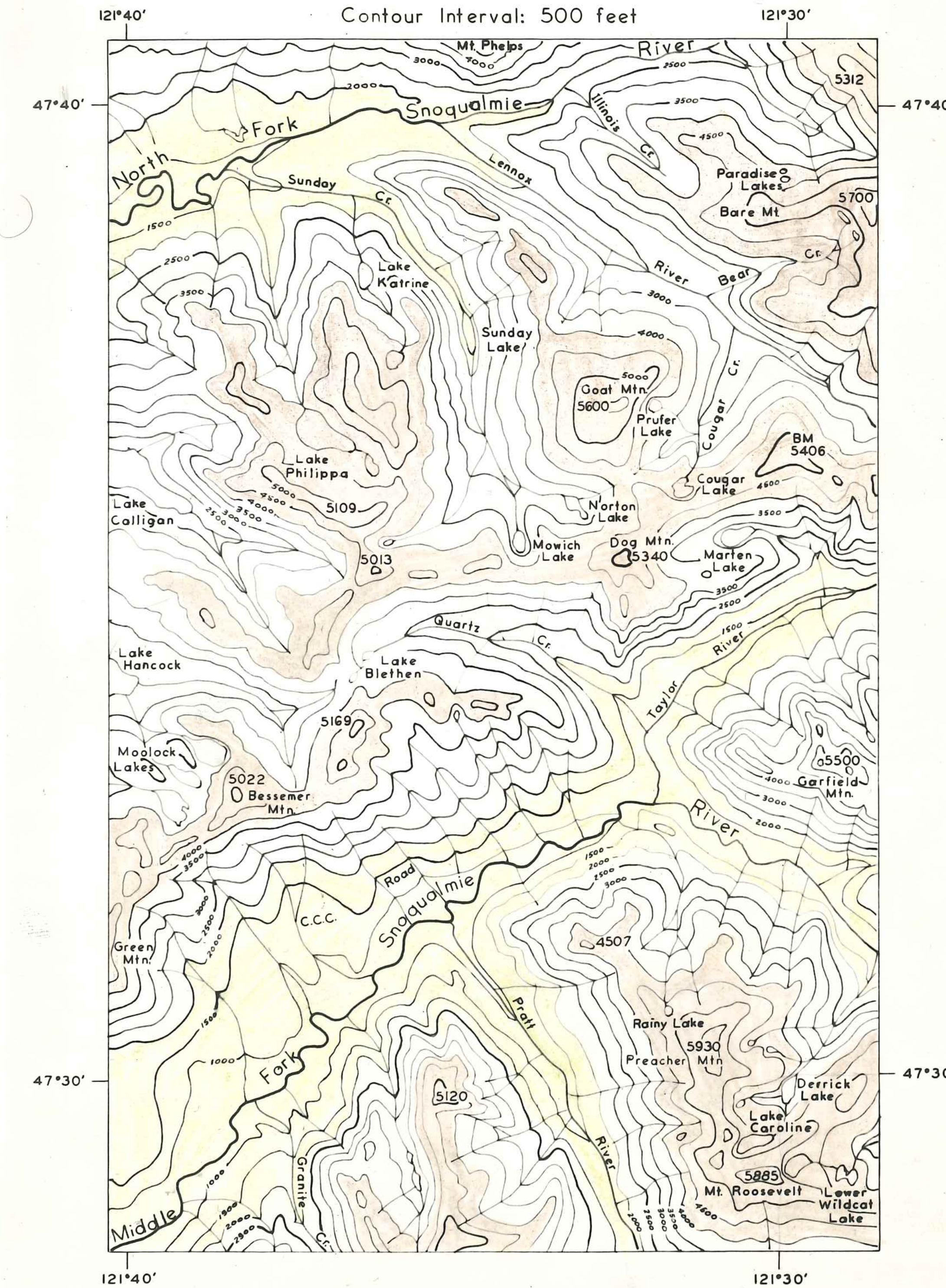
Topography and Drainage

The southeastern part of the Sultan quadrangle lies in the western part of the Cascade Range. The entire area is mountainous, with the only flat areas being the flood plains along the North and Middle Forks of the Snoqualmie River. The highest peaks are in the eastern part of the area. These include Mt. Roosevelt at 5885 feet and Preacher Mountain at 5930 feet in the southeast, Mt. Garfield at 5500 feet in the east central part of the area, and Goat Mountain at 5600 feet and Bear Mountain at 5700 feet in the northeast (cf Plate 2). The lowest parts of the area are the valleys of the North and Middle Forks of the Snoqualmie River, which are from 1000 to 1500 feet elevation through most of the area. Since these rivers have fairly low gradients in their lower courses, the relief becomes greater as the mountains become higher in the eastern part of the area where several summits are over 4000 feet above the valleys of the major rivers.

The valleys of these major rivers have been severely glaciated and are broad and U-shaped. They are never over a mile wide and are widest at junctions with important tribu-

PLATE 2

SOUTHEASTERN PART OF THE
SULTAN QUADRANGLE
King County, Washington
Scale
1 ½ 0 1 mile
Contour Interval: 500 feet



The mountainous areas above 4000 feet elevation are shown in brown while the valleys below 2000 feet elevation are shown in green.

taries such as the Taylor and Pratt Rivers along the Middle Fork and Sunday Creek along the North Fork of the Snoqualmie River.

Cirques heading in steep walls are common at altitudes above 4000 feet. At some places these cirques meet to form knife-edged ridges while in other places remnants of the preglacial upland are present. Features resulting from glaciation are discussed more completely in a later paragraph.

Where the ridges are at lower elevations, such as in the northwestern corner of the map area timber reaches to the summits and the precipitous slopes common in the higher glaciated regions are absent.

The southern two-thirds of the map area is drained by the Middle Fork of the Snoqualmie River and its tributaries. An important tributary is the Pratt River, a rapidly flowing stream fed by numerous side streams heading in high cirque lakes. It drains an important part of the southern third of the map area. Granite Creek is a sizeable stream which enters the Middle Fork of the Snoqualmie River in the southwestern part of the map area. A considerable portion of the east-central part of the region drains into the Snoqualmie Middle Fork through the Taylor River and through an important tributary of the latter, Quartz Creek.

The northern third of the map area is separated from the southern two-thirds by a divide running in a northeasterly direction. It includes such peaks as Green Mountain at 4890 feet, Bessemer Mountain at 5022 feet, and Dog Mountain at 5406 feet. Drainage of this northern third of the map area is by means of a number of tributaries to the North Fork of the Snoqualmie River. Important tributaries from west to east are Big Creek, Sunday Creek, and the Lennox River.

Both the North and Middle Forks of the Snoqualmie River show an uneven grade with stretches of relatively little fall alternating with stretches of swift water and fairly rapid fall. One of the more noticeable stretches of low gradient is along the North Fork of the Snoqualmie River near the mouth of Sunday Creek. Here numerous meanders and deserted meanders, and one ox-bow lake are present (of Plate 3). Farther downstream, outside of the map area, the river cascades through a rather narrow canyon with no meanders. Some meanders and cut-offs are present along the Snoqualmie Middle Fork also, but the stretches of low gradient are short and the meanders poorly developed, while numerous rapids exist between these stretches of quieter water.

The control of drainage pattern by jointing and faulting is evident at numerous places. Thus the mineralized fault zones at the Lennox, Devil's Canyon, Jack Pot, Beaverdale, and Goat Mountain mining properties all have all or part of their length traversed by small streams. In the central portion of the map area the minor tributaries of the Middle Fork of the Snoqualmie River form a parallel drainage pattern in a northwest-southeast direction. Likewise, the small tri-

PLATE 3

This aerial photo of the North Fork of the Snoqualmie river shows the wide valley near the mouth of Sunday creek, with numerous deserted meanders. This is a temporary graded condition since above and below the section shown in this photo the gradient of the river is much steeper.

butaries of the Taylor River near Mt. Garfield are in this same direction and the fault which controlled the course of one of these tributaries was exposed where it crossed the divide south of Norton Lake (cf Plate 4). The fact that the Pratt River and also the valley of the Middle Fork of the Snoqualmie River upstream from its confluence with the Taylor River also are in this same general direction suggests that they too may owe their present courses in part to a similar fault control.

Glaciation

Most of the higher valleys have cirques at their heads. In many cases these cirques are occupied by beautiful mountain lakes, such as Lake Caroline, Lake Philippa, Cougar Lake, Upper Wildcat Lake, and others. Most of the valleys show the typical stepped profile of glaciated valleys and in some valleys two basins at different elevations each contain a lake, for example, Lake Katrine and Little Katrine, Lower and Upper Wildcat Lakes, and Derrick and Caroline Lakes.

In some cases glacial erosion by the advancement of cirques is far advanced, and basins several miles long with steep sides extend from the major river valleys into the intervening upland. Examples of these large basins are those along Bear Creek, Cougar Creek, and the basins at the head of Lake Hancock and Lake Calligan. In such cases the ridges at the head of these basins are narrow, often knife edged ridges. In other

PLATE 4

Many small streams have their courses controlled by jointing or faulting. This photograph shows a fault surface on the divide south of Norton Lake along the course of a minor tributary of the Taylor River.

cases the cirques advancing into a ridge cause one side of the ridge to drop off abruptly for many hundreds of feet to the floor of the cirque while the other side of the ridge will slope off rather gently to a stream valley with no cirques developed. Such assymetrical ridges are present between the basins occupied by Norton and Mowich Lakes and the valley of Quartz Creek, and also between the basin occupied by Rainy Lake and the valley of the Pratt River.

Some similar assymetrical ridges occur which have stream valleys on the steep side rather than cirques. Examples are the steep cliff forming the south side of the Lennox River valley just above its confluence with the Snoqualmie North Fork, the cliff on the southwest side of Quartz Creek, the cliff on the southwest side of Illinois Creek, and numerous others. The cause of these steep slopes seems to have been a nivation or freeze and thaw process at the edge of snow accumulations in these valleys. The steepest slopes are on the shaded sides of the ridges where the snow persisted longer.

In the case of the larger valleys such as those of the North and Middle Forks of the Snoqualmie River, the Taylor River, and Pratt River, the relative proportion of steepening of valley sides and widening of valley floors by sapping and nivation and by corrasion of moving ice is unknown. However, the fact that neither hanging valleys nor morainal deposits are conspicuous, and that often the valleys will show steepening and faceting of spurs on only one side leads the writer to believe that sapping and nivation played a big role also in shaping the valleys of the major rivers. Taylor (13), from his observations of glacial erosion now active in Antarctica, saw no reason why a relatively stagnant glacier, filling a normal river valley, could not ultimately give rise to faceted walls and a typical catenary profile by sapping at its margin and erosion of ice marginal streams. Some grinding away of rock by ice seems necessary to produce the rock flour now present as glacial clays along the valley of the Middle Fork of the Snoqualmie River.

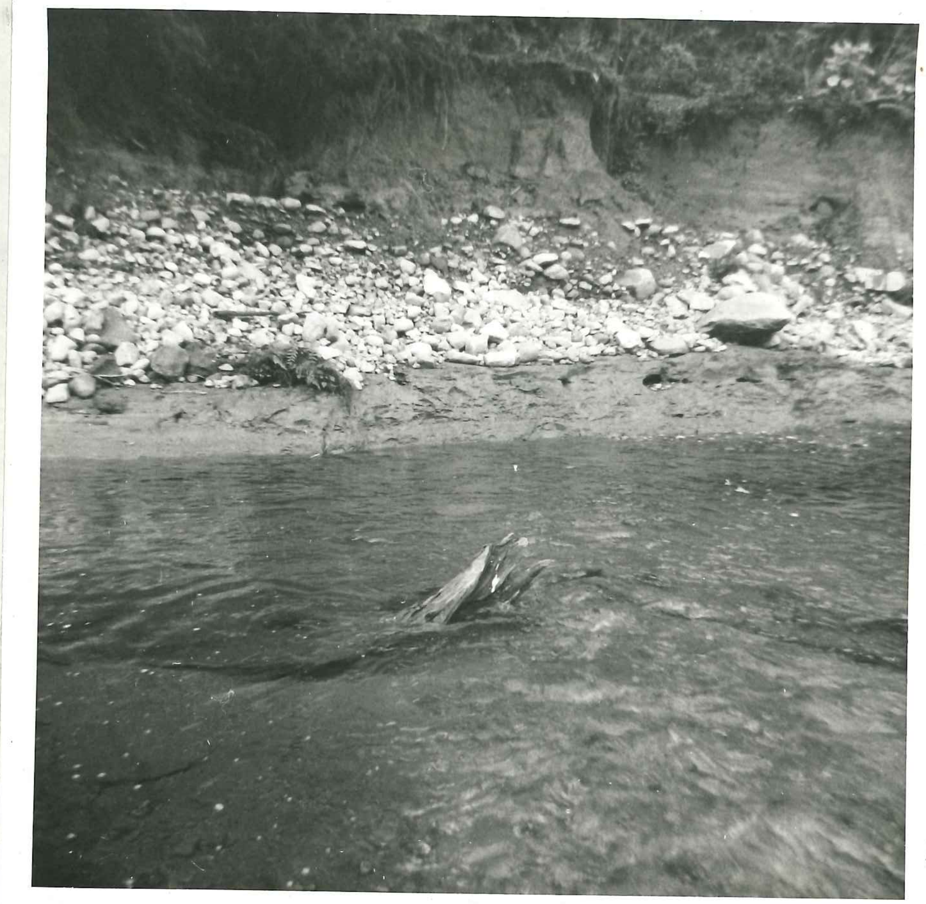
Nivation is still active in the higher altitudes which explains the fact that some glacial features have been so little modified in post glacial time. An example which might be cited is that of the dissection of Mt. Garfield. That peak when viewed from the air shows knife like ridges and many steep slopes bare of vegetation. Where snow drifts can accumulate they form small basins by nivation. The melting of snow in these small basins forms a supply of water for the freeze and thaw process to cut out large gullies. These gullies extend from the snow patches to the nearest river or stream and their size is out of proportion to the amount of water that normally flows in them. In these gullies most of the material moves down by gravity.

The rather slight climatic change necessary to increase the erosional activity was illustrated by the severe winter of 1948-49. At that time extremely heavy snowfall in the winter months was accompanied by numerous slides. The slides stripped the soil and timber in their path causing freezing and thawing processes to increase their activity on the bare rocks thus exposed. One of these slides piled up snow twenty to thirty feet deep along the Taylor River at 1300 feet elevation which persisted into the middle of the summer. During this same summer compacted snow remained in Devil's Canyon off Cougar Creek at elevations above 3200 feet until early fall, and the top of this snow was liberally sprinkled with rock which had fallen from the sides of the canyon. During that year of 1949 many of the peaks near 5000 feet elevation had small snow fields which had not melted away by the time the next winter's snows began. Thus it appears that a long succession of winters not much more severe than those of 1948-49 could result in important accumulations of snow at high elevations and the movement of that snow to lower elevations by slides, accompanied by greatly accelerated erosion.

Evidence for the existence during the Pleistocene of a lake in the valley now occupied by the Middle Fork of the Snoqualmie River is seen in the presence of remnants of glacial clay within this area. These clays are well exposed near the lower end of the Quartz Creek logging road, and along the southwest side of the Middle Fork opposite Mt. Garfield, where under-cutting of the river has caused the top soil and trees to move on the soft wet clays with a resulting land-slide topography. Additional exposures occur at scattered points along the southeast bank of the Middle Fork of the Snoqualmie River below the Taylor River (cf Plate 5), and northwest of the river on the lee side of the small island of rock extending into the glacial and alluvial deposits near the point where the St. Regis logging road crosses the Middle Fork of the Snoqualmie River.

As has been ably reasoned by J. Hoover Mackin in his study of the glaciation of the region around North Bend (6), this lake was impounded by the damming of the mouth of the valley now occupied by the Middle Fork of the Snoqualmie River by continental ice reaching to about the vicinity of Granite Creek. At this point the farthest advance of the continental ice is marked by a large moraine. This moraine is partly removed by the cutting of the Middle Fork of the Snoqualmie River, but a portion of the moraine still remains. To an observer looking down the valley from any elevated spot such as Nordrum Lookout it is strikingly apparent as a broad flat topped bench extending into the valley of the Middle Fork from the northwest slope of the river opposite Granite Creek. The material composing this moraine is exposed on the Granite Creek logging road and is seen to be mainly rocks of local derivation, rather than rocks carried down the valley of the Middle Fork of the Snoqualmie River by valley glaciers. J. H. Mackin attributed this morainal material to erosion from the surrounding mountains at the margin of the continental ice. The top of the moraine is at approximately 1400 feet elevation.

PLATE 5



Photograph showing glacial clays overlain by coarse river gravel along the Middle Fork of the Snoqualmie River.

This corresponds with the elevation of some terraces along the Middle Fork of the Snoqualmie River east of Mt. Garfield and also along the Pratt River, and may indicate that this was the level of the lake for a considerable period of time.

Climate

The climate in this vicinity of the Cascades is essentially the product of three factors: the high elevation of the Cascade Range, the presence of the ocean to the westward, and the prevailing south to west winds bringing moist maritime air from the sea against the mountains.

To the west and southwest of the area covered by this thesis are the Puget Sound Basin and the Olympic Mountains. The moist maritime air moving from the Pacific Ocean during winter storms before reaching this area must either move from the west across the Olympic Mountains or move from the southwest up Puget Sound through the broad Chehalis Valley which forms a gap in the Olympic Range. Westerly winds impinging on the high slopes of the Olympic Mountains cause extremely heavy rainfall on the western slopes of these mountains and in so doing the air loses part of its moisture. As a result, the precipitation in the map area is less than for areas of similar elevation on the western slopes of the Olympic Mountains. The fact that the precipitation is still very considerable is due to the fact that the westerly winds pick up more moisture on crossing Puget Sound, and also winds from the south can bring moist maritime air from the ocean through the gap in the mountains occupied by the Chehalis River, and northward up Puget Sound with little loss of moisture. These south to southwest winds impinging on the western slopes of the Cascade Range cause heavy precipitation.

The important effect of topography on precipitation is seen in a comparison of climatological data for the ten year period from 1935 to 1944, for the three stations at Seattle, Snoqualmie Falls, and Snoqualmie Pass. Seattle is near sea level, whereas the town of Snoqualmie Falls is along the Snoqualmie River west of the area included in this thesis, at an elevation of 430 feet. Snoqualmie Pass is southeast of this thesis area, at an elevation of 3010 feet, and precipitation there is typical of portions of the thesis area at a similar altitude. The yearly averages of precipitation, in inches, were 31.9, 51.4, and 92.2 for Seattle, Snoqualmie Falls, and Snoqualmie Pass, respectively. At high elevations much of the precipitation in the winter months is in the form of snow, and at Snoqualmie Pass during the ten year period under consideration the average annual snowfall was 363.9 inches. This snow normally reaches depths of ten to twelve feet in the highest basins, and locally much greater depths where it accumulates by snow slides at the foot of steep slopes.

During the summer precipitation is less than during the winter and there are many sunny days. The air is usually moist, but an occasional east wind, bringing warm dry air from

Plate 6

COMPARISON OF ANNUAL PRECIPITATION IN INCHES AT SEATTLE, SNOQUALMIE FALLS, AND SNOQUALMIE PASS FOR THE TEN YEAR PERIOD 1935 TO 1944 (2)

Year	Seattle Elev. 14'	Snoqualmie Falls Elev. 430'	Snoqualmie Pass Elev. 3010'
1935	31.55	47.25	87.36
1936	35.42	54.96	105.90
1937	43.86	67.65	125.04
1938	23.92	45.11	83.97
1939	33.12	54.55	93.84
1940	36.75	50.66	85.18
1941	34.56	54.30	82.72
1942	30.80	54.94	95.69
1943	26.86	46.32	84.13
1944	22.91	38.55	78.56
Average for 10-year period	31.9	51.4	92.2

east of the Cascades, will cause a drop in the humidity so that all logging operations in the area must be stopped because of the fire danger.

Vegetation

Being in a moist climate, the area included in this thesis has abundant vegetation. The type of vegetation varies considerably with the altitude. Along the valley floors and on the more gentle slopes up to 3000 feet elevation there are thick forests containing excellent Douglas fir and hemlock timber. Logging operations have removed much of this timber from the valleys of the Middle Fork of the Snoqualmie River and its tributaries the Pratt and Taylor Rivers, and in the past few years logging operations have begun along both sides of the North Fork of the Snoqualmie River.

Above 3000 feet elevation the timber thins out and hemlock, cedar and white fir predominate. Many of the talus slopes and glaciated surfaces with a thin soil cover have a covering of vine maple, or nettles where the ground is moist. Some of the higher open slopes are covered with huckleberry bushes and grasses.

DESCRIPTION OF ROCKS

Distribution of Rock Types

The geologic map (cf Plate 70) shows a large, rather complex formation consisting of graywackes, argillites, tuffs, and tuffaceous sediments outcropping in the western part of the area. This formation has been designated the Calligan formation after the exposures in the vicinity of Lake Calligan. An age of Cretaceous to Paleocene is suggested for the bulk of the Calligan formation on the basis of a similarity to formations in neighboring areas which contain fossil leaves, and also of the occurrence of worm tubes which resemble those found in other formations of that general age in western Washington. Within its map boundaries it could very well include some older rocks. However, there is no evidence of rocks of a different environmental facies that could be construed as a base to the Calligan formation. Thick accumulations of feldspathic graywackes and argillites occur in the vicinity of the Snoqualmie Middle Fork. Dark gray, fine grained graywackes are abundant near Sunday Lake and in the northwestern corner of the map area. To the north in the vicinity of Big Creek graywacke and shale beds are interbedded with andesitic to rhyolitic tuffs and tuffaceous sediments. Some of the massive fine grained tuffs within the sediments may be the direct product of volcanic explosions, but much of the tuff has been sorted by water and more or less mixed with other material.

With an increase in the amount of pyroclastic material the graywackes grade into tuffaceous sediments and finally into tuffs. In the vicinity of Mt. Phelps these tuffs are largely without stratification and accompanied by massive andesites. For purposes of mapping, the area of predominantly tuffs and andesites is shown separately from the area of essentially clastic sediments. However, in parts of the area where clastic and tuffaceous rocks are thinly interbedded no boundary can be mapped in the field and the dotted line shown on the map is largely diagramatic.

In the vicinity of Mt. Garfield along the Snoqualmie Middle Fork is another area of volcanic rocks, consisting principally of volcanic breccias. This group of rocks has been designated the Mt. Garfield Volcanics.

Younger dikes of andesitic to rhyolitic composition can be observed cutting the Calligan formation and also the andesitic and granitic rocks.

The granitic rocks include: the Preacher granite, a mass of leucocratic granite, partly granophyric, outcropping along the Middle Fork of the Snoqualmie River; the Quartz Creek complex on the northern end of the Preacher granite, in which rocks of quartz dioritic composition play an important role; a small area of biotite granite which outcrops along the North Fork of the Snoqualmie River surrounded by tuffs and graywackes; and, finally, granodiorite which is the most extensive rock in the area. The largest outcrop of granodiorite is in the northeastern part of the map area, but it also forms separate bodies along Granite Creek and in the vicinity of Mt. Roosevelt.

Sedimentary Rocks - Calligan Formation

General Features

The Calligan formation consists of a great thickness of graywackes, argillites, andesitic to rhyolitic tuffs and tuffaceous sediments. The formation outcrops along the western part of the map area from south of the Snoqualmie Middle Fork to the northern limits of the map. It also occurs locally as islands surrounded by later granodiorite, along the Lennox River and near Paradise Lake.

In the vicinity of the Middle Fork of the Snoqualmie River are outcrops of massive feldspathic graywackes and argillites. These graywackes consist predominantly of feldspar and quartz with a matrix which is chloritic in the less metamorphosed portions and is largely changed to biotite in the vicinity of the granitic masses. As the graywackes become metamorphosed some of the feldspar is replaced by quartz and the rocks become more quartzitic, but the original character of the rocks is apparent as the outcrops are followed to less metamorphosed areas.

No satisfactory estimate of the thickness of the graywackes and argillites in this vicinity can be made as the structure in the massive rocks is uncertain and much disharmonic folding and considerable faulting has occurred, in part presumably during emplacement of the neighboring granitic rocks. The base of the formation is nowhere exposed as all the contacts observed were either intrusive or fault contacts. The beds outcrop from 1000 feet elevation along the Snoqualmie Middle Fork to altitudes of 5000 feet on the divide separating the drainage basins of the North and Middle Forks of the Snoqualmie River, and the thickness is probably at least 5000 feet and possibly locally much more.

The coarse clastic rocks in the southern part of the area are quite feldspathic and rock fragments are few except where the rocks contain fragments of the associated argillites. In some other parts of the Cascades rocks similar to these have been called arkoses but due to the fact that these rocks in general have a chloritic matrix when not metamorphosed they are also referred to as graywackes.

As the formation is followed to the north the amount of volcanic material increases. Occasional beds of white fine grained rhyolitic tuffs representing ash falls are present, some of which are recrystallized to cherty appearing rocks. In the vicinity of Lake Calligan the coarse feldspathic graywackes contain andesite fragments and proceeding to the north and northeast of Lake Calligan the volcanic material becomes increasingly important, and the amount of chloritic matrix increases in proportion to the feldspar and quartz fragments. In the vicinity of Big Creek and on the Weyerhauser logging roads north of the Snoqualmie North Fork there are relatively thin bedded shales, graywackes, rhyolitic tuffs and tuffaceous sediments.

Near the mouth of Sunday Creek and on Mt. Phelps the tuffaceous material is largely without stratification and accompanied by massive andesites. Clastic sediments in this area are inconspicuous, and these rocks are described separately as the Mt. Phelps Volcanic Rocks.

Petrology of the Calligan Formation

For purposes of petrographic study the Calligan formation will be divided into (1) the graywackes, (2) the intraformational breccias, (3) the tuffaceous sediments, and (4) the argillites and shales. The metamorphism of these rocks adjacent to granitic areas will be discussed separately.

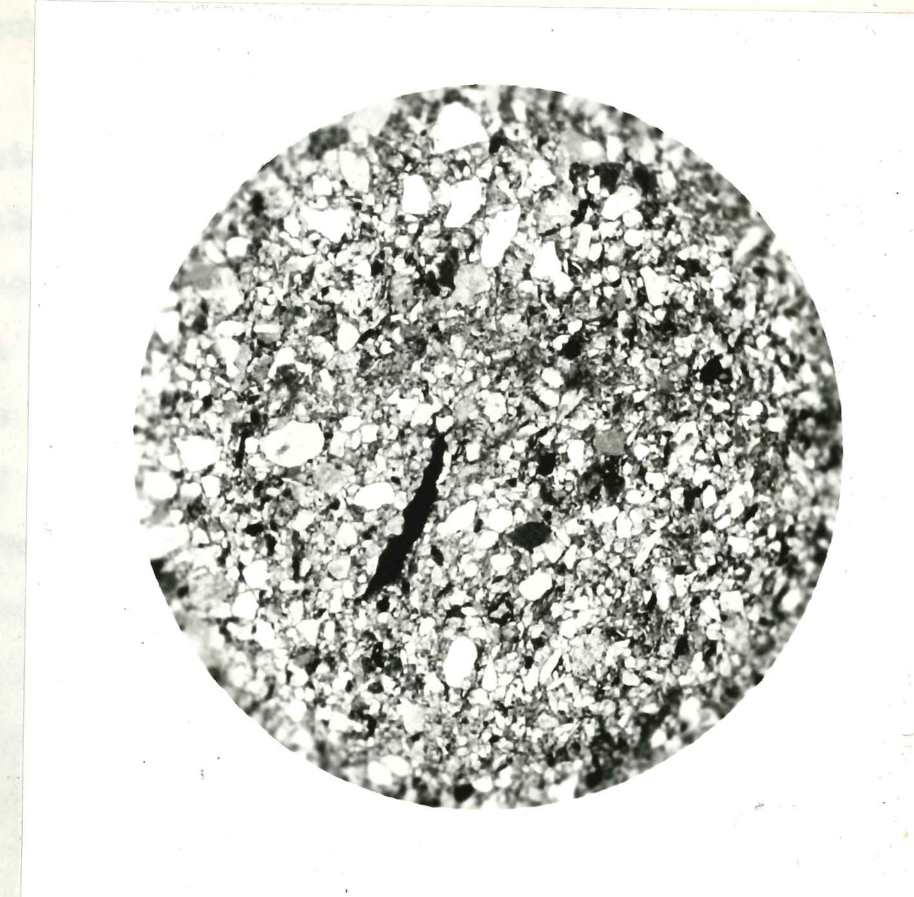
Graywackes

The graywackes are the most abundant rocks in the formation. They vary from fine grained, dark gray rocks of nearly uniform texture to coarser grained, light to medium gray rocks in which the larger clastic quartz and feldspar grains can be recognized by the naked eye. They weather to lighter gray or brownish gray colors. The coarser grained graywackes commonly include fragments of argillite. Where these fragments are abundant the rocks are treated separately as intraformational breccias.

The graywackes are usually massive and break with a more or less conchoidal fracture. In the northwestern part of the area they are exposed along the Weyerhauser logging roads in beds five to ten feet thick interbedded with fine grained, dark colored and sometimes thin bedded shales, and with light colored massive tuffaceous sediments (cf Plate 7).

Where these sediments suffer from much folding and faulting the massive graywacke beds act as competent members and the fine grained shales are folded disharmonically and

PLATE 7



Photomicrograph of a fine grained, dark gray graywacke from Big Creek showing angular quartz and feldspar grains and a considerable amount of chloritic matrix. Some fragments of andesite and shale are visible. (Plain light; x 12) often locally are squeezed out from between graywacke beds and accumulate at other places so that in the more disturbed areas the exact bedded nature of the formation is poorly defined.

Under the microscope the most conspicuous constituents are the clear, very angular grains of quartz. They make up twenty to forty per cent of the rock. Occasionally the grains show undulating extinction. In some cases this is due to later deformation of the beds but in a few cases in less disturbed portions of the formation a few grains of quartz will show these strain effects while the bulk of the quartz grains are unstrained. These few strained quartz grains are interpreted as being derived from rocks which had undergone deformation prior to their erosion and redeposition. Some of the quartz grains are spotted with small vacuole inclusions.

Less conspicuous but more numerous than the quartz grains are the angular grains of feldspar. The predominant variety is oligoclase, but some orthoclase grains and an occasional grain of microcline are present. Under the microscope the feldspar grains are seen to be mostly cloudy with alteration products. Some, however, are quite clear and show good twinning. The alteration in most cases is an alteration to sericite, often with the release of finely divided quartz. In the more altered graywackes the feldspars commonly lose their original outlines with the small plates of the chlorite in the matrix penetrating the margins of the feldspars.

Rock fragments make up a variable percentage of the graywackes. They include fragments of andesites and tuffs (cf Plate 8), including some recrystallized tuffs, plus fragments of argillite or shale formed from subaqueous erosion of the associated fine grained rocks.

All of the above constituents are contained in a fine grained matrix which usually makes up less than twenty-five per cent of the rock. This matrix is predominantly chloritic, with greenish flakes, needles and irregular patches of chlorite occurring between the other grains. The matrix also includes finely divided quartz and feldspar particles and some opaque particles which are probably partly clay. Also present are some small grains of pyrite and magnetite, epidote, and zircon. Sometimes elongated larger quartz and feldspar grains lie with their long axes in the direction of the bedding. As the graywackes become more disturbed and metamorphosed the chlorite changes to biotite and some incipient growth of biotite is usually present.

Intraformational breccias

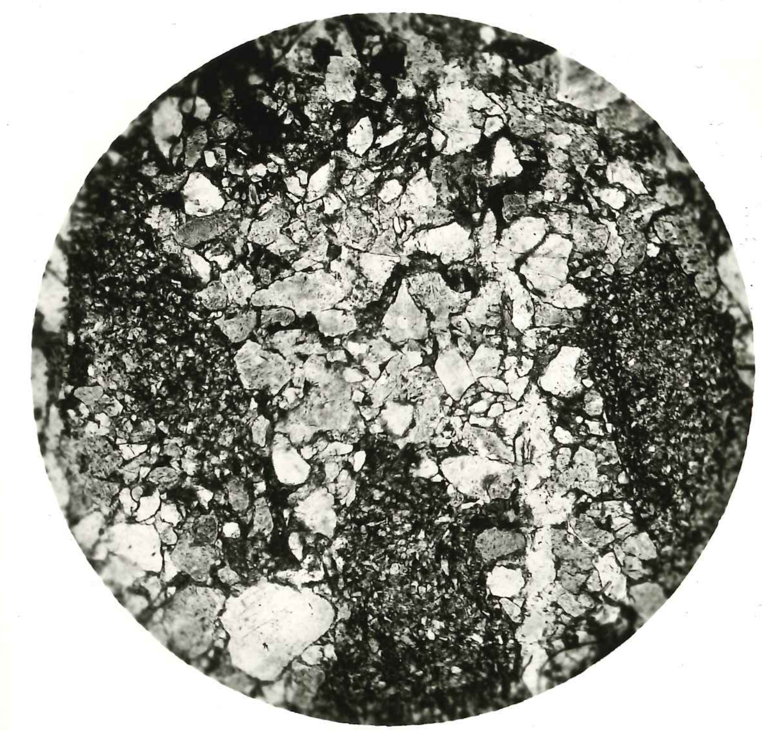
The intraformational breccias are coarse grained graywackes which contain appreciable amounts of fragments

PLATE 8

Photomicrograph of a coarse grained, light gray, fedspathic graywacke from the north shore of Lake Calligan showing angular grains of quartz and feldspar and a small amount of chloritic matrix. A fragment of andesite is visible in the center of the photo. (Plain light; x 12) of the associated fine grained argillites. These fragments are of the same composition, but of smaller grain size, as the graywacke matrix. This fact makes it extremely likely that these intraformational breccias were formed by the breaking up by subaqueous erosion of partially indurated beds of the associated argillites and finer grained graywackes, and their incorporation in the coarser grained graywackes. These fragments are always angular and range in size from one millimeter to one centimeter and occasionally larger. The proportion of these fragments varies from an occasional fragment up to nearly fifty per cent of the rock. They are often oriented with their long axes in the direction of the bedding. A photomicrograph of a thin section from a typical breccia occurring north of Lake Calligan is shown in Plate 9.

Since the thermal metamorphism of portions of the Calligan formation changes the megascopic appearance of the graywackes, and since there are variations in the quantity of tuffaceous material from place to place, there was some question during the early stages of mapping as to whether all the sedimentary rocks should be included in one unit. As mapping proceeded it was found that the most distinctive rocks, which could be recognized both in the metamorphosed and unmetamorphosed state, were the intra-

PLATE 9

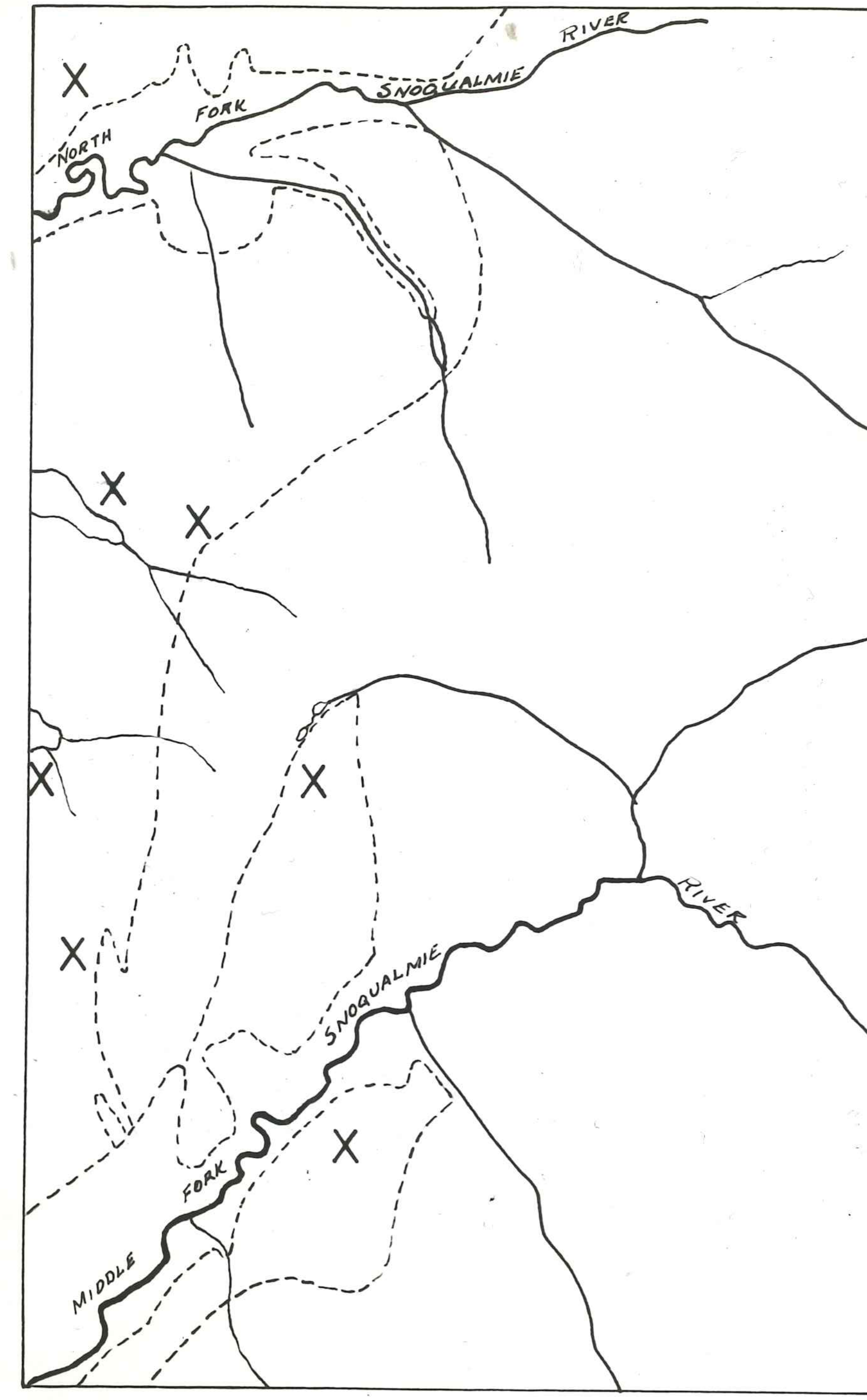


Typical intraformational breccia from ridge northeast of Lake Calligan. The fragments of fine grained argillite are of the same composition as the enclosing graywacke. (Plain light; x 12) formational breccias. The finding of outcrops of these breccias at scattered localities throughout most of the area underlain by sedimentary rocks, as shown in Plate 10, was of great assistance in showing that the graywackes occurring throughout the area were deposited under similar conditions and therefore could be considered as one unit, part of which was metamorphosed. These breccias do not occur as blanket deposits and therefore can not be used as a stratigraphic marker, but only as a sort of lithologic guide to the formation as a whole.

Tuffaceous sediments

The tuffaceous rocks vary considerably in appearance and texture from place to place. Their color varies from light yellowish gray to dark greenish gray, in some cases with considerable variation in a single specimen. In the northwestern part of the map area, on both sides of the North Fork of the Snoqualmie River, the tuffaceous rocks are interbedded with graywackes and shales (cf Plate 11). A thin section of a specimen from one of the tuffaceous beds seen in the photograph shows a few larger grains of quartz and orthoclase and fragments of micropegmatite in a fine grained tuffaceous base which makes up the bulk of the rock (cf Plate 12). This fine grained base appears as an indistinctly polarizing aggregate of quartz, feldspar, and chlorite, with a mosaic texture, and the rock has apparently suffered some recrystallization. The fact that the

Plate 10

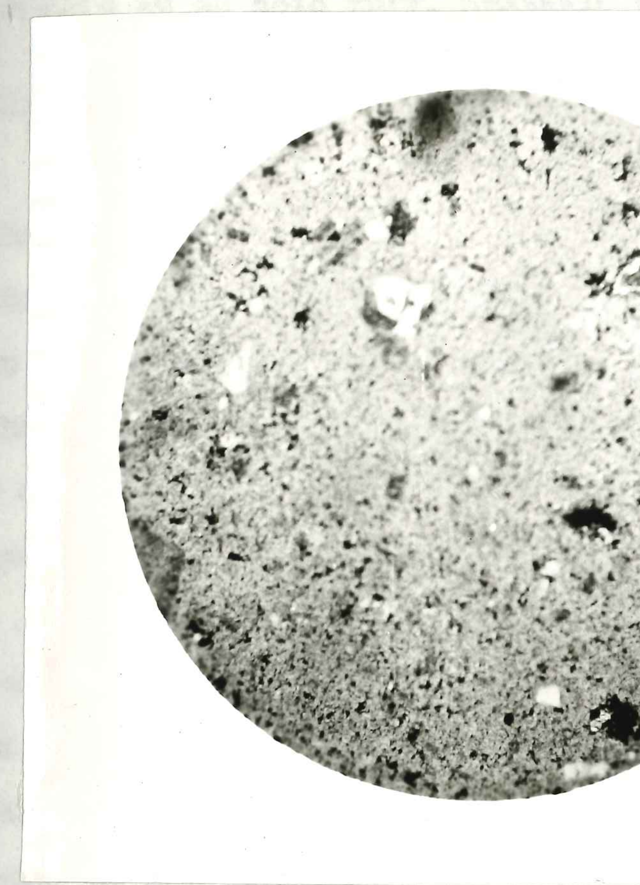


Intraformational Graywacke Breccias are one of the distinctive rocks of the Calligan formation. "X" marks the locations of observed outcrops of these rocks, within the outcrop area of the Calligan formation and the associated volcanic rocks.

PLATE 11

Photograph of light colored massive water-laid rhyolitic tuffs with an included pod of shale, along Weyerhaeuser logging road up Big Creek. During deformation the massive tuffaceous layers act as competent members and the shales are squeezed out at some spots and accumulate at others.

PLATE 12



Photomicrograph of water-laid rhyolitic tuff from interbedded tuffs and graywackes along Big Creek (cf Plate 11). Fragments of quartz are contained in a fine grained tuffaceous groundmass. (Plain light; x 12)

adjacent argillite is relatively unaltered illustrates the relative ease with which the fine-grained tuffaceous rocks are recrystallized. The light color and abundant quartz would class this as an acid tuff, probably rhyolitic.

Argillites and shales

The argillites are dark gray to nearly black rocks. In the northwestern part of the area they are relatively unaltered and often thin bedded, and are best called shales. These shales are usually sheared and quite fissile. Closer to the granitic bodies these finer grained rocks become very hard and break with a conchoidal fracture and are best called indurated argillites.

Along the western boundary of the map area, and still better exposed outside the boundary along Weyerhauser logging roads west of Lake Hancock are considerable thicknesses of the black friable shales. A specimen of these shales from the vicinity of Big Creek contains some coarser grained fragments in the fine grained shale. A thin section of this rock shows the coarser fragments to be pieces of graywacke in which all of the grains show evidence of much strain. The breccious appearing rock can be interpreted as resulting from deformation. The thin layers of graywacke originally interbedded with thick layers of shale were broken up during deformation and scattered through the shale.

Some of the argillites show a tendency toward graded bedding. This often is rather hard to see in a hand specimen but shows up sharply in a thin section as shown in the photomicrograph (cf Plate 13) of a specimen from the St. Regis logging road along the Snoqualmie Middle Fork. Although the clastic texture is still plainly visible here, the rock has a spotted character due to the development of incipient porphyroblasts of a mineral which is probably feldspar, and thus has suffered some metamorphism.

Metamorphism of the Calligan Formation

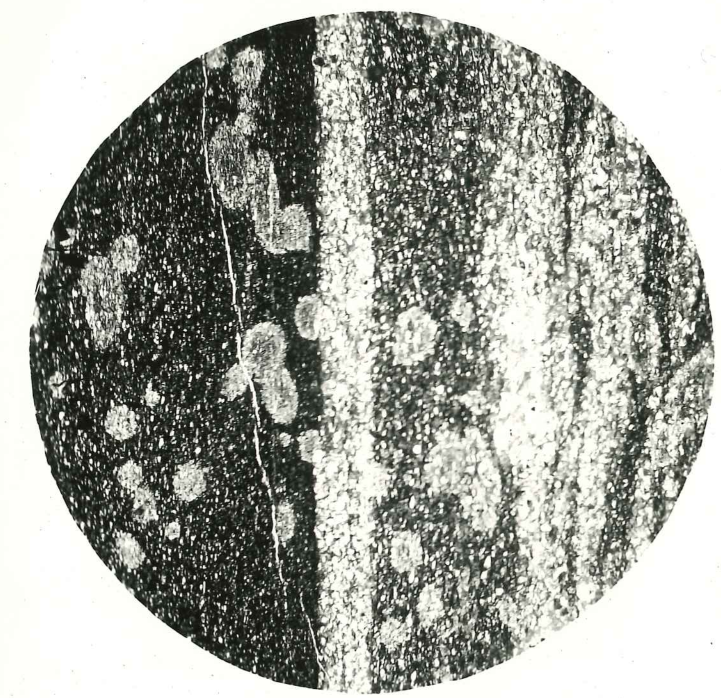
As stated previously, there is some recrystallization in the fine grained tuffaceous rocks and development of chlorite in the matrix of the graywackes throughout the area, but it is only where thermal metamorphism has been active near the granitic masses that the rocks are strongly metamorphosed.

Metamorphism of the graywackes

The larger quartz grains are the last to lose their clastic appearance and thus the coarse grained graywackes are the least changed in appearance of any of the rocks of the Calligan formation. Considerable thicknesses of these metamorphosed graywackes are exposed along and above the CCC road on the north slope of the Snoqualmie Middle Fork. In these rocks the larger quartz grains often still retain their angular shape although there has been some overgrowths and coalescence of neighboring grains. Many of the quartz grains have crenulated borders.

The matrix of the graywackes has been recrystallized

PLATE 13



Photomicrograph of argillite from the road along the Middle Fork of the Snoqualmie River, showing graded bedding. The spots are incipient porphyroblasts, probably feldspar. (Plain light; x 12) with development of aggregates of biotite. The smaller quartz and feldspar grains have recrystallized and coalesced so as to produce a mosaic texture. The large feldspar grains have lost most of their clastic appearance and are often hard to tell from newly formed grains of oligoclase which develop in the rock. However, the latter usually do not show twinning and contain numerous inclusions. There are in places thin layers around this crystalloblastic feldspar in which coarse grained biotite has concentrated as if during the growth of the feldspar the biotite had been pushed out.

Quartz veinlets are numerous and they often have selvages of biotite on both sides indicating some solutional transfer of materials within the rock during metamorphism. Locally intense deformation has caused fracturing of the larger grains and stringing out of the biotite and in these rocks the original clastic texture is almost completely obliterated.

The total result of the metamorphism is to produce a light purplish gray rock consisting essentially of quartz, feldspar and biotite, with a granulose texture, which is best called a biotite granulite. The coarse grained feldspathic graywackes in some localities are even more transformed, as will be described in connection with the Quartz Creek Complex and the Preacher Granite.

Metamorphism of the tuffaceous sediments

In these rocks metamorphism has caused more strongly marked changes than in the graywackes. In the metamorphosed areas of the Calligan formation there are associated with the granulites and hornfelses some dark green, usually somewhat banded rocks, composed essentially of hornblende. These amphibolites are the metamorphic equivalents of the basic tuffaceous rocks. There are other rocks containing both biotite and hornblende along with granular quartz and feldspar, which were derived from rocks which were intermediate between graywackes and tuffs. These latter rocks tend to green or greenish gray colors, often mottled, as contrasted with the purplish tints of the metamorphosed graywackes.

Metamorphism of the very fine grained siliceous tuffaceous rocks produces dense hard rocks, white to pale green in color, which break with a conchoidal fracture. These rocks resemble cherts and their true nature was revealed by the finding of fragments of graywackes within them which still retained their clastic texture. Epidote in the form of irregular grains and veinlets is common in the metamorphosed tuffaceous sediments as well as in the metamorphosed tuffs and andesites.

Metamorphism of the argillites

The most noticeable change in the argillites during metamorphism is a marked induration. They are no longer fissile but break with a conchoidal fracture. Also there is a development of fine grained biotite which replaces the chlorite of the argillite causing these metamorphosed rocks to have a dark purplish gray color in contrast to the dark greenish gray or nearly black color of the unmetamorphosed argillites. In the more advanced stages of metamorphism these dense metamorphosed argillites are best called hornfelses.

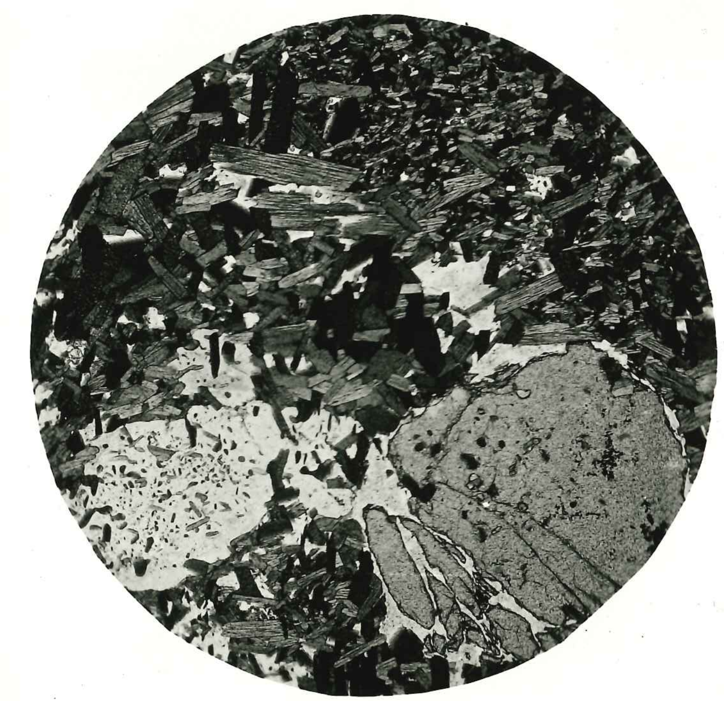
In the hornfels the small clastic quartz and feldspar grains have recrystallized and also grown by coalescence, and thus lost their original outlines. Commonly there develop fairly large amoeba-like porphyroblasts of oligoclase containing numerous inclusions. Some quartz generally forms small disconnected veinlets which stand up as small ridges on the weathered surface of the hornfels. There appears to be some release of iron in the form of magnetite during the transformation of chlorite to biotite as this mineral is abundant. A thin section of a hornfels from the slope north of the Snoqualmie Middle Fork shows a diamond shaped tetrahedron of magnetite within a grain of biotite.

In the immediate contact zone some narrow bands within the metamorphosed argillites show a development of well formed red garnets. These were noted near the portal of the tunnel on the Langer mining claims, on the ridge between Paradise Lake and the head of Illinois Creek, and south of Sunday Lake (cf Plate 14).

Stratigraphy

The outcrop pattern on the geologic map suggests that the Mt. Garfield Volcanics occupy a synclinal area and are younger than the feldspathic graywackes in the southern part

PLATE 14



Photomicrograph of biotite granulite from near contact of Snoqualmie granodiorite south of Sunday Lake. A large porphyroblast of garnet is visible along with feldspar and much biotite. (Plain light; x 12) of the area (of regional structure).

As stated above, there is an interbedding of graywackes with the Mt. Phelps volcanic rocks in the northwestern part of the area and fragments of andesites are present in the feldspathic graywackes in the vicinity of Calligan Lake. However, these andesite fragments are scarce south of Lake Calligan and andesite dikes cutting the Calligan formation are only conspicuous in the localities where volcanic rocks now outcrop. Those dips that can be obtained in the Calligan formation in the northern part of the area suggest that there may be an increase in volcanic admixtures in the Calligan formation upward in the section as well as laterally toward the north.

General statement

No fossils except some worm tubes were found despite a diligent search of all likely outcrops. In similar formations elsewhere in the Cascades the chief fossils have been leaves contained in shaly members. In this area nearly all the shales have suffered extreme deformation due to disharmonic folding, and fossil leaves would thereby be destroyed.

Some early workers have assigned some formations in the Cascades to the Paleozoic on the basis of metamorphism and this probably accounts for the inclusion of the area covered by the Calligan formation in the Carboniferous or older age group on the latest State of Washington Geological Map (1). Since it was found that most of the metamorphism observed other than the induration and development of chlorite in the graywackes was related to the emplacement of the Tertiary granitic bodies, metamorphism alone was not considered an indication of great antiquity.

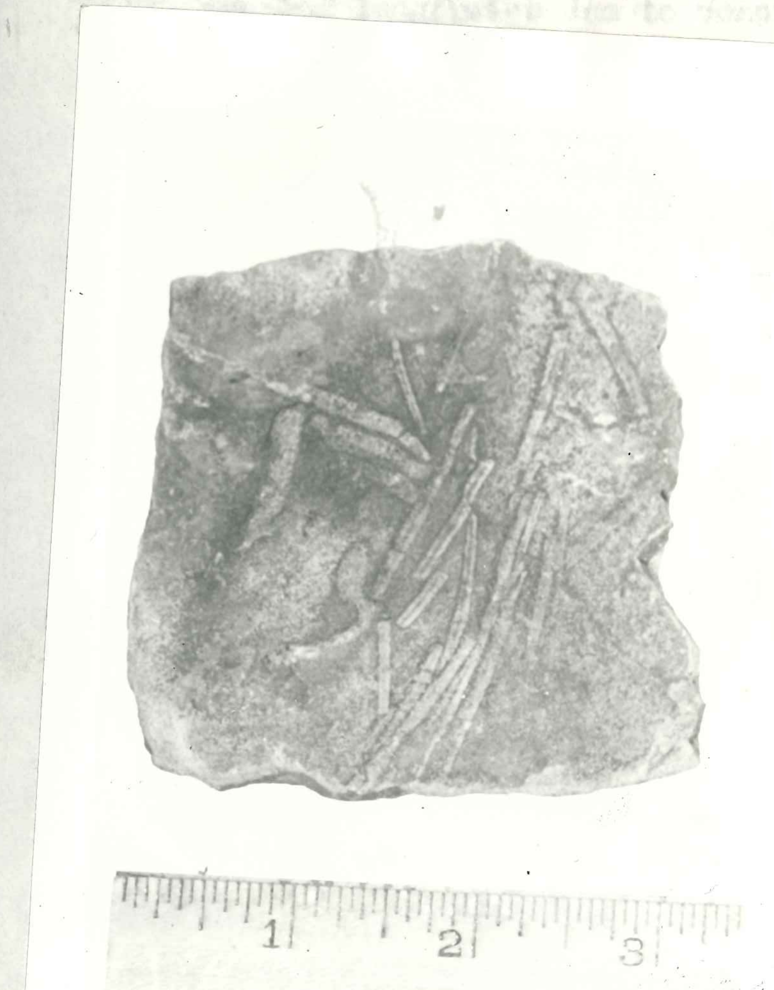
Since folding is chiefly of the disharmonic type, an unconformity to be valid must be of regional extent, accompanied by a change of facies, and the actual contact must be observed. No such unconformity was recognized. The entire sedimentary assemblage outcropping in the western portion of the map is considered part of the same environmental facies and therefore is mapped as one unit.

Worm tubes

Some worm tubes were found on the weathered surface of an outcrop of indurated sandy argillite of the Calligan formation on the ridge separating the two branches of the creek which enters Lake Calligan from the southeast. The tubes are straight or very slightly curved and appear to be formed of cemented sand grains slightly coarser than the surrounding argillite. They average about an inch long and one-sixteenth inch in diameter, and usually have a single longitudinal groove due to a cracking of the tube (cf Plate 15). They stand up as ridges on the weathered surface.

As noted by W. R. Danner (4), who found similar worm tubes north of the map area in the vicinity of Sultan, Washington, and also in the Sol Duc formation on the Olympic Peninsula, these worm tubes are identical with those from Kodiak Island,

PLATE 15



Photograph of worm tubes on weathered surface of sandy argillite.

Alaska, described and illustrated by E. O. Ulrich (14) of the Harriman Alaska Expedition. Ulrich describes the worm tubes from Kodiak as being not over 2.3 millimeters in diameter and to be usually cracked lengthwise due to compression, giving the same longitudinal groove that is present in the Lake Calligan occurrence. These Kodiak tubes were named Terebellina palachei after a member of the expedition. J. C. Reed and R. R. Coats (9) describe the occurrence in graywackes from Kruzof Island, Alaska, of Terebellina palachei with Aucella crassicollis, a Lower Cretaceous pelecypod. Whether these tubes are of stratigraphic value, however, still remains to be proven.

Comparison of Calligan formation to sedimentary rocks in neighboring areas

Some geologists who are familiar with the clastic sediments of northwestern Washington have recognized the rocks of the Calligan formation as being similar in lithology to some of the Cretaceous and early Tertiary formations. For example, Dr. P. Misch noticed a resemblance of some of the feldspathic graywackes to parts of the Swauk formation outcropping to the east and to some rocks occurring in the Guye formation. Both Dr. H. Coombs and Dr. H. Wheeler of the University of Washington noticed a resemblance of the graywackes and especially the intraformational breccias to similar rocks in the Sol Duc formation outcropping in the Olympic Peninsula. The Sol Duc formation is itself of uncertain age, but is known to be older than the Metchosin basalt of Eocene age, and is considered by various geologists as either earliest Tertiary or Cretaceous. In view of this resemblance it was considered of some significance that Terebelline palachei was found in both formations.

The earliest publication on the stratigraphy of this vicinity of the Cascades was the pioneering work of G. O. Smith and F. C. Calkins in the Snoqualmie folio, published in 1906 (8). The northwest corner of the area covered by this folio joins the southeast corner of this thesis map area in the vicinity of Lower Wildcat Lake. Smith and Calkins describe rocks ranging from schists to relatively little altered volcanic rocks and sediments, and make the difference in metamorphism the basis for a subdivision between the older or pre-Tertiary and the younger, or Tertiary, formations. The pre-Tertiary rocks, all outcropping east of Snoqualmie Pass, consist of some mica and hornblende schists, called the Easton schist, some black slates designated the Peshastin formation, and some metamorphosed volcanic rocks named the Hawkins greenstone. Since no paleontological evidence was available, Smith and Calkins assigned these rocks to the Carboniferous or older on the basis of metamorphism.

Early Tertiary clastic sediments are shown outcropping over a considerable area in the eastern half of the Snoqualmie folio. These include two arkosic formations, the Swauk and Naches, which were considered by Smith and Calkins as contemporaneous but to have originated in separate basins, since the Naches formation contains a large amount of intercalated basaltic tuffs and some rhyolite, called the Kachess rhyolite. The Naches is but one of several formations in the Cascades where clastic formations considered near the same age as the Calligan formation contain intercalated volcanic material.

In the vicinity of Snoqualmie Pass Smith and Calkins mapped three rock units as Miocene. These include: (1) The Guye formation, consisting of grits, arkoses, shales, small amounts of chert and limestone, and some interbedded basalt and rhyolite. The Guye formation covers an area of about thirty square miles starting a short distance southeast of Lower Wildcat Lake. (2) The Keechelus andesites, covering an extensive area on the Snoqualmie folio map and consisting chiefly of pyroxene andesite and dacite, with some rhyolite and basalt. (3) The Snoqualmie granodiorite, which is later than both of the above formations and includes some biotite granite and quartz diorite as well as the more abundant granodiorite.

From the Guye formation Smith and Calkins obtained some fossil leaves, two species of which were identified by Dr. F. H. Knowlton as probably Miocene in age and a third as resembling a species from the Fort Union (Paleocene) formation of Montana. It was Smith and Calkins' opinion that if it were not for the Miocene age assigned these fossil leaves they would have made the Guye formation early Tertiary because of its similar lithology to the Swauk and Naches formations. While there has been no publication to this effect, geologists such as Dr. P. Misch and Dr. H. Coombs, who are familiar with this portion of the Cascades, have considered the Miocene dating of the Guye formation to be in error and an early Tertiary age to be more probable.

Of the formations described in the Snoqualmie folio the Easton schist nowhere outcrops far enough west to be expected within the map area. Although the most recently published geological map of the State of Washington shows the sedimentary formations within the area covered by this thesis in the same color and symbol as the Peshastin formation of the Snoqualmie folio the results of this thesis show that the rocks are closer in lithology to the Tertiary formations of the Snoqualmie folio than to the Paleozoic Peshastin formation which outcrops east of the Cascade summit. Of the Tertiary formations described by Smith and Calkins, the arkosic portions of the Guye formation resemble some of the feldspathic graywackes of the Calligan formation, especially in the southern part, and both formations locally contain associated volcanic rocks. It is believed these two formations may be nearly contemporaneous and of early Tertiary or perhaps Cretaceous age rather than Miocene as the Guye is shown in the folio.

In 1913 W. S. Smith (11) mapped the rocks in the Skykomish quadrangle, which lies northeast of the map area and due north of the area included in the Snoqualmie folio mentioned above. He describes certain rocks under the name of the Easton schist, and shows them outcropping in the northeastern portion of the Skykomish basin near the summit of the Cascade Range. As the next younger formation, he describes a metamorphic series, the Peshastin formation, occurring north of the northeastern corner of the area covered by this thesis, as consisting of quartzites, schists, and crystalline limestones with associated greenstones. Smith dated this formation as Ordovician on the evidence of fossils obtained from a cherty part of a limestone lens outcropping two miles west of Grotto. W. R. Danner (5), in an investigation of numerous limestone lenses outcropping in a belt which includes these mentioned by Smith, found some Permian fusilinids on Palmer Mountain near Grotto, which illustrates the diversity of ages of rocks in the Cascade geosyncline. The small area of metamorphic rocks in the vicinity of Paradise Lake in the northeastern corner of this thesis map area is an extension of the Peshastin formation as mapped by Smith. However, the rocks in question which are hornfelses, amphibolites, and metavolcanics, could very well be the result of metamorphism of interbedded argillites, graywackes and tuffaceous rocks similar to those outcropping farther west and mapped as the Calligan formation (cf above). The only rocks in this group of metamorphics which are different from the metamorphosed portions of the Calligan formation to the west are some dense black argillites outcropping above Paradise Lake. They resemble the small outcrop of black argillite on the southwest slope of Mt. Garfield. Also near the southwest corner of Paradise Lake is an outcrop of breccia identical with some of the coarse volcanic breccia near the base of the Mt. Garfield volcanics along the Taylor River and Quartz Creek. Smith included the Mt. Garfield volcanics in his Keechelus formation which he assigned to the Miocene. Therefore, if any of the fossiliferous rocks observed by Smith and Danner near Grotto extend into this area they must form only a part of a greater assemblage which is chiefly composed of much younger rocks.

In the Skykomish Basin northeast of the map area Smith mapped a large outcrop of arkosic sandstones, shales and conglomerates, the shaly members of which contained fossil leaves which could be correlated with the flora of the Fort Union formation (Paleocene) of Montana. He called this formation Swauk because of its similarity to the Swauk formation mapped by Smith and Calkins in the Snoqualmie Quadrangle. His description of a typical sandstone is as follows:

> It is fine grained, gray, mottled with brown specks. As primary minerals there are quartz, plagioclase and orthoclase; as secondary minerals or alteration products, chlorite, kaolin, epidote, sericite and quartz. The grains vary in size up to one-half millimeter and are bound together with quartz, clayey material, and chlorite.

It is apparent from the above description that the rock has a chloritic and argillaceous matrix and is not greatly different from some rocks of the Calligan formation, namely the feldspathic graywackes which are relatively free of volcanic admixtures and not metamorphosed.

Smith shows on his map several disconnected areas of volcanic rocks, all of which he designates as Keechelus formation of Miocene age. At some localities dikes of andesite were observed cutting the Swauk formation. Included in his Keechelus andesites are the volcanic rocks of Mt. Garfield, but unfortunately these volcanic rocks do not contact the clastic rocks.

Because of the similar lithology of the Swauk formation of the Skykomish basin and of those Calligan graywackes free of volcanic material, it becomes of interest to investigate the relation of volcanic rocks to the sedimentary formations of the Swauk type elsewhere on the west side of the Cascades. North of the Skykomish basin mapped by Smith, is an area of rocks mapped by Weaver (15) in the vicinity of Index. His oldest rocks are a series of schists, slates, crystalline limestones and cherts which he has called the Gunn Peak formation and thought to be of Carboniferous age. Among the Tertiary rocks Weaver describes a "West Index Andesite Series" consisting of a complex mass of intercalated layers of fine grained andesite breccias, conglomerates and badly altered lavas. Their age is uncertain but Weaver has noted a close resemblance to a series of andesites which he had found to be quite extensive farther to the west, south of Monroe, and which underlie the marine Oligocene of the Puget Sound Basin and overlie the Eocene brackish water beds. Weaver therefore thought the West Index andesite series might be of late Eocene age. He also found a formation of limited extent consisting of five to seven hundred feet of coarse angular arkosic conglomerate, with interbedded tuffs, lavas and andesite breccias, which he called the Howard arkose. He mentioned the possibility that it was of the same age as the West Index andesite series but thought it probably was younger, possibly Miocene.

Farther to the north J. E. Spurr (12), in a report on the ore deposits of Monte Cristo, Washington, shows a similar section to that within this thesis area. He summarizes it as follows:

Ancient granitic rock, not exposed	
Arkoses and conglomerates with some quartzites	Mesozoic
Earlier andesites and tuffs	Eocene
Tonalite	Miocene
Rhyolite	"
Basaltic rocks	"
Pyroxene andesites, tuffs, etc.	"
	Pliocene

Spurr found his arkoses to contain fragments of andesite. He explains this as follows:

> On the west side of Wooden Creek the attitude of the arkose series makes it apparently overlie the volcanic series, consisting of andesite, basalts, etc., which lies to the northeast; but since the basalts which lie next to the arkoses seem to be intrusive into them the apparent relation indicated by the attitude is probably misleading and is perhaps to be explained by a fault along Wooden Creek. The fragments of andesitic rock found in the arkoses therefore probably belong to older volcanics, associated with the ancient granite.

In a later paragraph Spurr reports the finding of a single fossil on the mountain slopes northeast of Glacier Creek. His description is as follows:

> The rock (containing the fossil) is a fine dark green arkose slate or tuff with layers of conglomerate containing pebbles of andesite and fine impure sandstone. It is probable that this horizon lies well up in the andesite series, although on account of the confusion introduced by the plicated structure of the region it is probable that its position is lower. The single fossil was found by Mr. W. T. Stanton to be Corbicula pugetensis, which was originally described from the Puget Group at Carbonado, Washington . . . . The Puget group was at first supposed to be Cretaceous, but later study by Dr. Knowlton of the fossil flora places it probably in the upper Eocene or lower Miocene. From all the data which we have therefore we may class the andesite series as lower Miocene.

However, later work by Weaver (16) on the Tertiary formations of Western Washington shows Corbicula pugetensis to be Eocene. Since Spurr has also considered his arkose to be Eocene, and since he describes the andesite boulders as being in an arkosic matrix, and also mentions the occurrence of andesite fragments in his arkoses it would seem that his early andesites could be nearly contemporaneous with the arkoses. Thus a similar relation seems to exist here as was found in the vicinity of Mt. Phelps, between the Mt. Phelps volcanic rocks and the Calligan formation.

Conclusions regarding age
of the formation

A comparison of the rocks of the Calligan formation with rocks of the neighboring areas may be summarized as follows:

(1) No rocks have been found which could be definitely correlated with the Paleozoic formations of the neighboring areas, although it is probable some older rocks are included in the area mapped as the Calligan formation, especially in the northeastern part, and not recognized.

(2) It is not unusual in the Cascades to find volcanic material interbedded with clastic rocks of the arkose-graywacke type.

(3) Disregarding the conflicting terminology of arkose and graywacke, the portions of the Calligan formation which are relatively free from volcanic material are of similar lithology as the Swauk formation described by W. S. Smith, the arkosic portions of the Guye formation described by Smith and Calkins, and the arkosic formation of Monte Cristo described by Spurr.

(4) On the basis of the worm tubes and the similarity of the lithology to the Swauk type sedimentary rocks, the portion of the Calligan formation from Lake Calligan to the Snoqualmie Middle Fork, where the rocks are relatively free of volcanic admixtures and very feldspathic, is dated with considerable confidence as Cretaceous to Paleocene.

(5) Since some of the massive feldspathic graywackes in the vicinity of Lake Calligan contain andesite fragments the volcanic activity must have begun during the same period, Cretaceous to Paleocene. However, structural evidence indi-

cates that volcanic activity in both the northwestern part of the area and in the vicinity of Mt. Garfield continued past the period of deposition of the feldspathic graywackes.

Volcanic Rocks

Distribution

Volcanic activity was widespread in the area and apparently lasted for a considerable length of time. There are two large areas of volcanic rocks plus some dikes of more recent age. The bulk of the volcanic rocks are concentrated in two localities, around Mt. Garfield in the south and around Mt. Phelps in the north, and are described separately as the Mt. Garfield Volcanics and the Mt. Phelps Volcanics. Neither of these accumulations of volcanic rocks are entirely within the map area, and, in fact, those in the vicinity of Mt. Phelps are only a part of an extensive area of volcanic rocks north of the map boundary. Both of these volcanic accumulations represent old volcanic centers and the rocks in them are largely of subaerial deposition and poorly stratified. The Mt. Phelps Volcanics are andesitic to rhyolitic in composition and grade into water laid tuffs which are interbedded with the graywackes and argillites of the Calligan formation. In this same area later andesite and dacite dikes cross-cut the interbedded tuffs and sediments.

The volcanic rocks in the vicinity of Mt. Garfield are mainly andesite breccias, but there are some massive andesites.

The volcanic rocks extend beyond the map area on the east. On the west they stop near the Taylor River at the boundary of the Preacher granite but a few scattered outcrops of coarse andesite breccia outcrop north of the CCC road to the west of this granite mass. Similar breccias were observed in the northeastern part of the map area near Paradise Lake. These coarse breccias are usually associated with some banded greenstones or amphibolites formed by metamorphism of fine grained volcanic rocks. Along the CCC road and about four miles west of the mouth of the Taylor River are several outcrops of andesite porphyry within the Calligan formation which appear to be large dikes intermediate in grain size between diorite and andesite. They have been metamorphosed along with the Calligan argillites and feldspathic graywackes.

While the structural relations (cf regional structure) suggest that the Mt. Garfield Volcanics are younger than the feldspathic graywackes of the Calligan formation, there seems no reason to separate the two units by any great period of time; therefore the writer believes the volcanic activity in the vicinity of Mt. Garfield began at least as far back as early Tertiary time. It is possible some of the Mt. Garfield Volcanics are the equivalent of some of the rocks mapped as Keechelus in the Snoqualmie quadrangle (8).

Some later andesite and dacite dikes cut the Preacher granite between the Snoqualmie Middle Fork and Rainy Lake and also along Quartz Creek.

Mt. Garfield Volcanics

In the vicinity of Mt. Garfield the andesitic rocks re exposed over a vertical distance of more than 4000 feet rom the Taylor River to the top of Mt. Garfield. The most bundant of the andesitic rocks is an aphanitic dark greenish ray, massive rock, which usually appears somewhat lighter ray on a weathered surface. It consists of a variable mount of fragments of andesitic lava and earlier tuff in a atrix of finely divided andesitic tuff. In these tuffs the ragmental character of the rock is usually best seen on a eathered surface. Next in abundance are the massive ande-ites, some porphyritic. The outline of their outcrops is sually irregular and locally they seem to transect andesitic uffs. Some are fairly coarse grained with a holocrystalline roundmass and probably represent dike like masses, whereas thers are porphyritic with an aphanitic to nearly amorphous roundmass and were probably flows.

Although many of the rocks have a fragmental texture here is an almost complete absence of visible bedding. Prob-bly this could be due in part to subsequent alteration during placement of the neighboring granitic rocks, but large areas way from the granitic rocks are only weakly altered and it s certain some bedding would have been preserved if it had ver been present. The limited distribution of the rocks oupled with the predominance of pyroclastics, the great thick-ss exposed, and the absence of any stratigraphic sequence suggests that the rocks represent material which has accumulated around a volcanic center.

The same andesitic tuffs outcrop in a small area north of the Taylor River above 1800 feet elevation on the ridge between the Taylor River and Quartz Creek. Above the Quartz Creek logging road a small outcrop of fine grained quartz biotite granulite and dark gray fine grained quartz diorites of the Quartz Creek Complex are overlain by a massive fine grained dark gray recrystallized tuff. This tuff forms a cliff several hundred feet high visible from the road.

Just south of the Taylor River near the eastern boundary of the map between 1600 and 2700 feet elevation there is an outcrop of volcanic breccia containing some blocks over two feet in diameter set in a matrix of andesitic tuff. Some of the blocks are andesite, while others are fragments of banded pyroclastics and tuffaceous sediments. In a creek a few hundred yards to the west of the breccia outcrops there is a coarse grained tuffaceous appearing rock which includes some one-fourth to one-half inch fragments of granite containing quartz and orthoclase intergrowths. These granite fragments and numerous embayed and brecciated quartz and feldspar crystals are contained in a dense, almost amorphous groundmass, which has been highly sheared and slightly recrystallized. The fragments of granitic rock are too small to positively identify but they more closely resemble the Preacher granite than any of the other granitic rocks now exposed in the map area.

In these fragmental rocks there is no evidence of any sorting of the coarser or finer materials and no stratification is visible. No coarse breccia was observed at a higher elevation than 2700 feet. While a lack of any stratification precludes a subdivision of the volcanic rocks it appears that the coarse volcanic breccia and the tuffs with granitic fragments belong near the base of the series.

Mt. Phelps Volcanics

Another area of volcanic rocks quite similar to those occurring on Mt. Garfield occurs on both sides of the North Fork of the Snoqualmie River below its confluence with the Lennox River. This area presents the same assemblage of volcanics as at Mt. Garfield, namely, massive andesites, coarse andesitic tuffs or breccias, fine grained tuffs, and tuffaceous sediments. There are more fine grained tuffs and less coarse tuffs here than at Mt. Garfield. The tuffs and tuffaceous sediments are intercalated with the shaly sediments and graywackes of the Calligan formation and some are rhyolitic in composition.

The area of volcanics is separated into several parts by the rather extensive alluvial deposits along the North Fork of the Snoqualmie River and along Sunday Creek. On the south the andesitic rocks are exposed along the ridge between Sunday Creek and the Snoqualmie North Fork. The region is heavily timbered and exposures are limited at low elevations

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The area of volcanics is separated into several parts by the rather extensive alluvial deposits along the North Fork of the Snoqualmie River and along Sunday Creek. On the south the andesitic rocks are exposed along the ridge between Sunday Creek and the Snoqualmie North Fork. The region is heavily timbered and exposures are limited at low elevations but going up this ridge an outcrop of massive green andesite is encountered at an elevation of 1700 feet, about 200 feet above the river level. These andesite outcrops continue at intervals in cliffs twenty to fifty feet high as the ridge is followed to a peak at an elevation of 3200 feet. These andesites are dark greenish gray, fairly coarse grained, and generally porphyritic with visible feldspar phenocrysts. They weather to light tan, green or brown colors. Some of them are large dike-like masses.

Beyond this peak at 3200 feet elevation the rocks are predominantly tuffs. Most of these tuffs are light greenish gray, with a porcelain like texture. They contain a few irregular fragments of coarser grained volcanic rocks. Going east into Section 18, south of the Lennox mine, an increasing amount of argillite is intercalated with the tuffs. This argillite sometimes shows fairly good bedding, striking between north and N30°E and dipping nearly 90°. The intercalated tuffs and argillites finally end at a contact with quartz diorite.

On the steep north slope of the ridge overlooking the Lennox River and the Snoqualmie North Fork the tuffs mentioned above can be followed to the edge of the alluvium. At one place just south of the St. Paul and Tacoma logging road a large mass of rather coarse grained dark green porphyritic andesite can be seen cross-cutting fine grained porcellaneous tuff. At this point there also occurs some coarse breccia with fragments about one-half inch across, some of which are of granite and some of graywacke, contained in a matrix of porcellaneous tuff. The graywacke fragments appear quite fresh and the clastic texture is well preserved (cf Plate 16) while the tuffaceous matrix is hard and breaks with a conchoidal fracture like chert and has numerous patches and veinlets of epidote.

The same volcanic rocks outcrop on the north side of the river where they form the bulk of Mt. Phelps. The tuffs are more abundant than the massive andesites. To the east, below Mt. Phelps, these tuffs contact the Snoqualmie granodiorite which is often of quartz dioritic composition along this contact. Considerable alteration of the volcanic rocks accompanied the emplacement of the granodiorite and resulted in the formation of abundant yellowish green epidote in veinlets and patches and also considerable silicification and induration.

Occasionally some of the fine grained tuffs show some lamination but it is of such local extent and of such diverse strike and dip that it is of doubtful stratigraphic value. Some of the massive andesitic tuffs exhibit a coarse sheeted structure. This is illustrated by the photograph (cf Plate 17) taken in a canyon on the south side of Mt. Phelps. No attempt has been made to subdivide these volcanic rocks into stratigraphic units.

Mt. Phelps is at the east end of a long ridge which

PLATE 16

Photomicrograph of breccia near confluence of the Lennox River and the North Fork of the Snoqualmie River showing fragments of graywacke (left) and a fragment of granitic rock (right) in a groundmass of porcellaneous tuff. (Plain light; x 12)

PLATE 17

Photograph showing sheeting in massive tuffs on south side of Mt. Phelps.

separates the drainage area of the North Fork of the Snoqualmie River from that of the South Fork of the Tolt River. Going west from Mt. Phelps this ridge is composed of the same volcanic rocks as occur on Mt. Phelps. They comprise fragmental rocks and massive andesites. The tuffs are mostly light to medium gray or greenish gray. The massive andesites are usually dark gray or dark greenish gray, and though they are not conspicuously porphyritic their feldspars are usually visible as lighter colored crystals against a dull background. As the ridge is followed westward to near the section line between Sections 2 and 3, Township 25N, Range 9E, the tuffs contain numerous fragments of granite. These tuffs, except for the presence of the granitic fragments, are similar to the tuffs to the east.

While the bulk of the rocks described so far appear to have been above the water when they accumulated, the tuffaceous rocks from this point to the western edge of the map area are mainly in the form of tuffaceous sediments interbedded with shales and graywackes and have been described in conjunction with the clastic rocks of the Calligan formation.

The third part of the Mt. Phelps volcanic group occurs on the south side of the North Fork of the Snoqualmie River west of Sunday Creek. Exposures are very limited but outcrops and float indicate that the same andesitic tuffs which outcrop northeast of Sunday Creek also outcrop southwest of the creek. However, the massive andesites are lacking here and tuffs are

ercalated with some sediments and show some stratification.
; it would appear that here, as in the northwestern part
the map area we are dealing with water laid tuffs and the
canic center was north of the river in the vicinity of Mt.
lps, where much of the material appears to have accumulated
ve water.

These tuffs, together with those previously described,
ear to form a rough circle around a small area of biotite
nite. This granite, which is described more fully in
nection with the granitic rocks, is exposed on the north
of the ridge between Sunday Creek and the creek flowing
of Lake Philippa.

Southward toward Lake Philippa the proportion of pyro-
stic material decreases and the rocks are best classified
h the sedimentary rocks. These tuffaceous sediments, with
e tuffs, can be traced westward to the vicinity of Big
ek. Here they are well exposed in a road cut on the Weyer-
ser logging road and are described in connection with the
iments. But along this road, just at the western edge of
map area, is an irregular area of volcanic breccia less
n a mile across. The tuffaceous sediments here are rela-
ely flat lying with small open folds and minor faulting.
breccia appears to break through these sediments with
hly inclined boundaries and with no evidence of stratifi-
ion. It is not greatly altered and consists of fragments

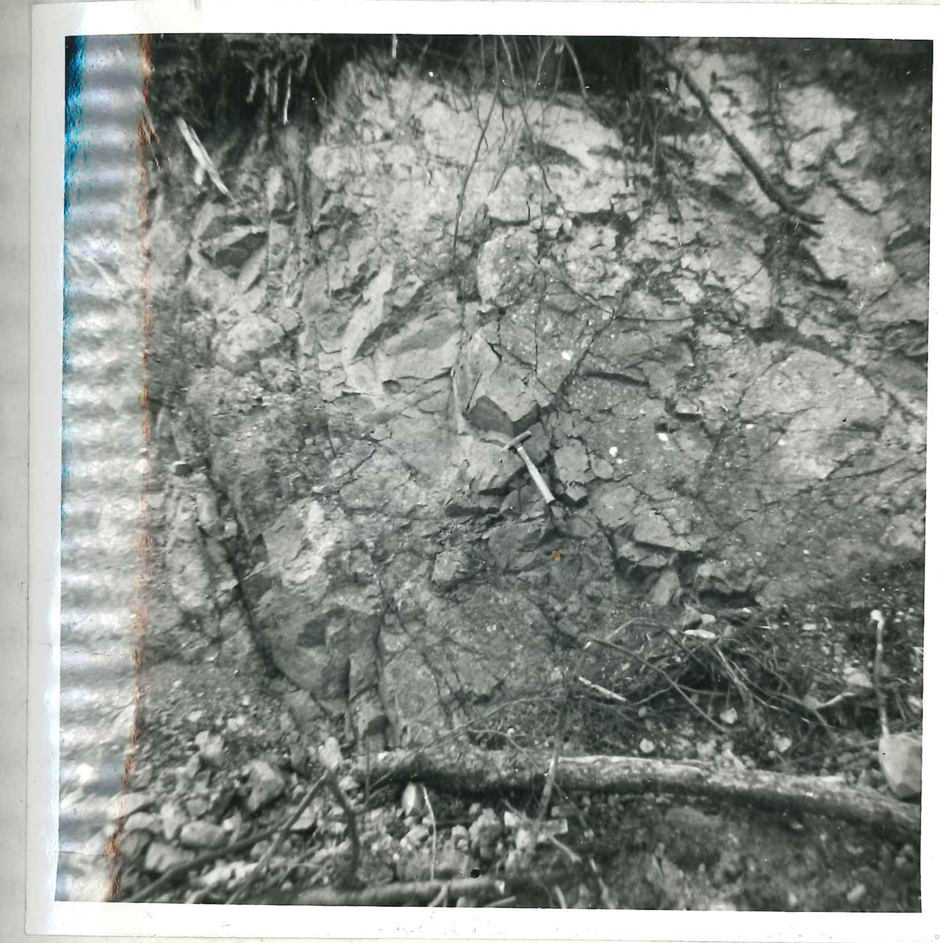
less than an inch across of pyroclastic material and also fragments of the friable shales which are included as small lenses between the massive tuffaceous sediments at this point. These fragments are inclosed in a very fine grained partly amorphous tuffaceous matrix. At one place the breccia is cut by a two-foot dark brown andesite dike (cf Plate 18).

Petrography of the Andesites

The massive andesites in the area around Mt. Garfield and the area around Mt. Phelps are essentially the same, although those in the vicinity of Mt. Phelps are in places more highly altered. The andesites are usually, although not always, porphyritic, and the feldspar crystals are easily detected by eye. When fairly fresh the andesites appear crystalline and break with an uneven fracture. They are dark gray or dark greenish gray in color, and weather to lighter gray or brown. The specific gravity averages 2.85.

The feldspar of the andesites is some variety of andesine. These feldspars form tabular crystals which are usually elongated into laths in the case of the smaller crystals. The small laths usually show no twinning or only carlsbad twinning. The larger crystals are usually twinned after both the carlsbad and albite laws. The feldspars usually are slightly zoned, the outer rim being slightly more sodic. The boundary between the zones is not abrupt or well marked as in the case of the zoned crystals of the granitic

PLATE 18



Photograph showing andesite dike cutting volcanic breccia along logging road up Big Creek.

rocks, nor does the albite constant vary more than a few per cent.

The hornblende occurs as phenocrysts about one millimeter across, and as small grains or needles in the groundmass. Some of these needles in the groundmass are extremely small, of green color, and are often enclosed in feldspar crystals. The larger hornblende crystals vary in color from brownish green to bluish green. Both varieties are pleochroic. The brownish green variety has Z = dark green, Y = green, and X = pale brown. The bluish green variety has Z = greenish blue, Y = green, and X = greenish yellow, and the extinction angle Z:c is eighteen degrees. Some of the bluish green variety is definitely of secondary origin as it is seen to occur along fractures.

Quartz and orthoclase are absent. There are variable amounts of iron ores present. Magnetite is most common, and forms either shapeless grains or small diamond shaped octahedrons. Pyrite is sometimes quite abundant, especially in the more altered specimens.

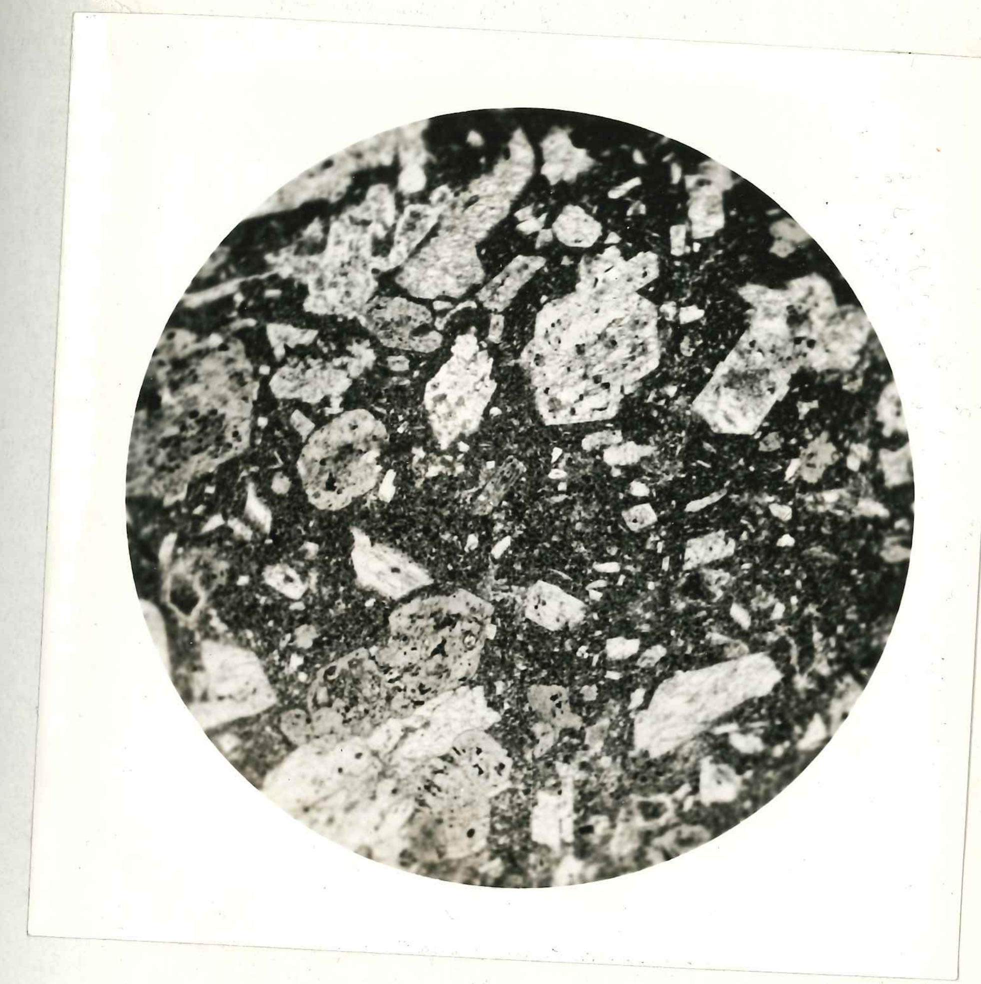
The andesites vary considerably in grain size. Although the majority are holocrystalline, some have an exceedingly finely divided groundmass, which was probably originally partly glass. Fragments of these finer grained andesites are common in the Mt. Garfield tuffs and one such andesite outcrops in the bed of a creek which flows down the north side of Mt. Garfield and empties into the Taylor River two miles above its mouth. This andesite is porphyritic (cf Plate 19), with phenocrysts of andesine feldspar ($An_{42}Ab_{58}$) and green hornblende, set in a very dense, partly amorphous base.

An example of one of the coarser grained andesites is that mentioned earlier as occurring in an irregular mass cross-cutting tuffs south of the St. Paul and Tacoma logging road along the North Fork of the Snoqualmie River between the Lennox River and Sunday Creek. Although this rock is megascopically like the other andesites it shows in thin section a more coarse grained texture almost identical in size with the average fine grained quartz diorites. It is porphyritic with phenocrysts of andesine feldspar up to two millimeters in size while the groundmass consists of grains of feldspar and hornblende averaging one-half millimeter in size. There are numerous grains of pyrite scattered through the groundmass. Much of the hornblende is fibrous and some of the hornblende grains pass into veinlets of hornblende, indicating that much of the fibrous hornblende is secondary. Some epidote is also present. Plate 20 shows a photomicrograph of an andesite porphyry from the west side of Mt. Garfield.

Petrography of the Andesitic Tuffs

The andesitic tuffs vary in color from dark to medium gray. With an increase in number and size of fragments they grade into andesite breccias. On the other hand, as they

PLATE 19



Photomicrograph of fine grained andesite from north slope of Mt. Garfield. Phenocrysts of andesine feldspar and hornblende are inclosed in a partly amorphous groundmass. (Plain light; x 12)

PLATE 20

Photomicrograph of porphyritic andesite from west side of Mt. Garfield. The phenocrysts are andesine feldspar and hornblende and the groundmass is holocrystalline and shows a development of much secondary hornblende and some recrystallization of the feldspar. (x-Nicols; x 12) become water laid instead of subaerial they grade into the tuffaceous sediments (cf Plate 21).

The tuffs and breccias are all very dense with no cavities. In the coarser grained tuffs or breccias the fragments are usually of a lighter color than the matrix. This is especially true of rocks containing fragments of granitic rock.

The matrix of the tuffs varies somewhat in grain size, but is usually very finely divided. Many of the andesitic tuffs on Mt. Garfield had an originally glassy base. This glassy matrix has been devitrified. In the less altered tuffs the matrix is exceedingly finely divided and indistinctly polarizing. In the case of the more altered tuffs the matrix shows a partial or total recrystallization. It then consists of a mosaic of small interlocking grains of feldspar with very irregular borders through which penetrate innumerable small needles of greenish hornblende. The feldspar appears to have a low birefringence as it gives only a gray interference color. Occasionally an imperfect albite twin can be seen and the extinction is usually almost parallel, which means the feldspar in the recrystallized tuffs is an oligoclase which is considerably more sodic than the feldspar of the andesites.

In certain of the fine grained tuffs such as those described from the cliff above the Quartz Creek logging road the entire rock has been thus recrystallized to form a fine grained feldspar-hornblende-biotite hornfels. In this rock

PLATE 21

Photomicrograph of water-laid tuff from ridge between Philippa Creek and Sunday Creek. Numerous andesite fragments are mixed with some clastic quartz and feldspar. (Plain light; x 12) there has also been an addition of some quartz which occurs in small scattered grains of irregular outline. A few of the feldspar grains have coalesced and grown to form larger porphyroblasts which have an amoeba-like shape and inclose many grains of hornblende. The biotite is deep brown and forms small grains about the size of the hornblende. Both the biotite and hornblende locally coalesce into porphyroblasts with a pronounced sieve texture (cf Plate 22) or into irregular patches or bands surrounding areas composed mainly of feldspar. This is apparently a case of metamorphic differentiation.

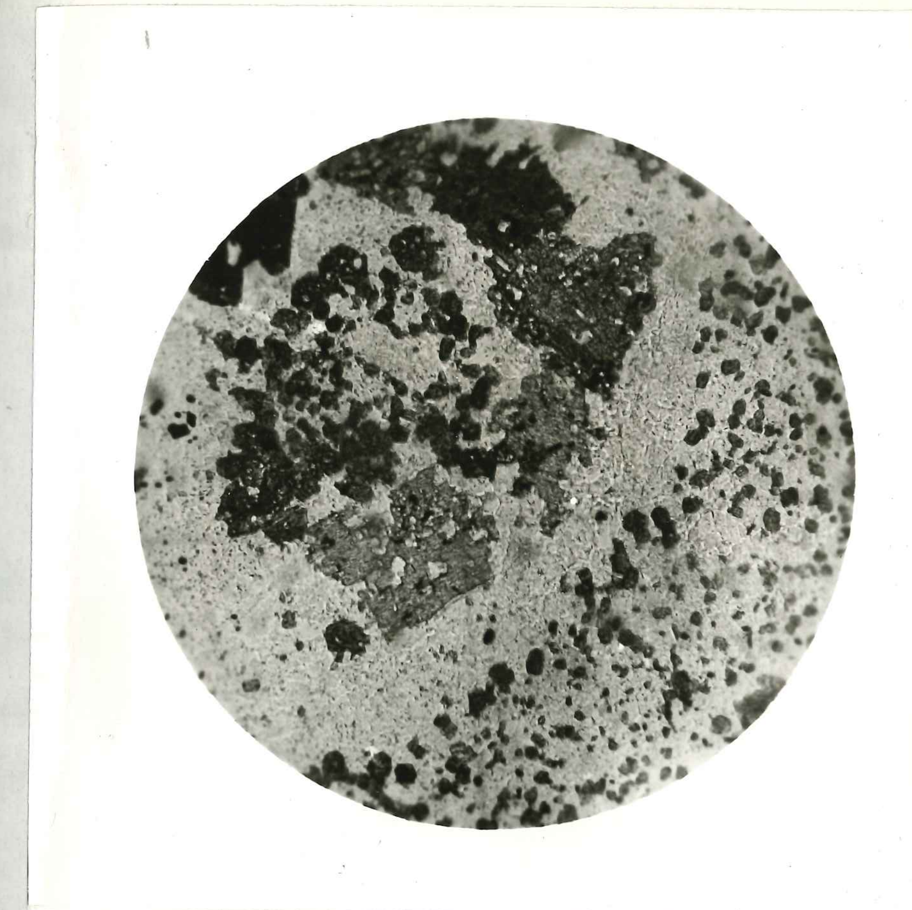
Andesite Dikes Cutting the Calligan Formation

A number of dark brown dikes one to six feet wide were observed cutting the Calligan formation near Big Creek (cf Plate 18). They are often vesicular with holes up to one-fourth inch in diameter. Under the microscope they show an intersertal texture, with small lath shaped crystals of andesine feldspar and a mesostasis of green chloritic material that was probably originally glass.

Andesite Dike in Bear Basin

On the southeast side of Bear Creek across from the Bear Basin Mining Company camp is an andesite dike in the granodiorite, striking nearly parallel to the silver bearing veins in the basin. The dike is a dense black hard rock. A

PLATE 22



Photomicrograph of recrystallized fine grained tuff from slope north of Quartz Creek logging road. There is a coarsening of grain size with coalescence of small hornblende and biotite grains into larger poikiloblastic grains and development of porphyroblasts of quartz and feldspar. (Plain light; x 50) thin section of the rock shows it to be andesite and finely porphyritic. The phenocrysts consist of plagioclase largely altered to calcite, and mafics largely altered to chlorite. The groundmass shows a pilotaxitic texture and is composed of a mass of small plagioclase laths locally in flow lines with some interstitial iron ores and greenish material, probably chlorite. The dike weathers to a brown color due to the abundance of iron.

Dacite Porphyries in Granodiorite Near Granite Creek

On the ridge east of Granite Creek are some light greenish gray fine grained porphyritic rocks, which are probably dikes, although their scattered outcrops in timber prevent their true shape from being determined. Under the microscope they are seen to be dacite porphyries of essentially the same composition as the surrounding granodiorite. They contain large subhedral phenocrysts of andesine feldspar, some fractured phenocrysts of quartz, and some mafics altered to chlorite. The groundmass is a fine grained granular aggregate of quartz, plagioclase, orthoclase and chlorite.

Dikes in Preacher Granite West of Rainy Lake

On the ridge between the Snoqualmie Middle Fork and the valley occupied by the creek flowing from Rainy Lake are some dikes of varying composition cutting the Preacher granite. These vary from dacite to andesite in composition. One dacite dike about twenty-five feet wide and dipping seventy degrees stands up as a ridge and exhibits good columnar structure (cf Plate 23). It has phenocrysts of quartz, orthoclase, plagioclase, biotite and hornblende in a fine grained microcrystalline groundmass (cf Plate 24). Some parts of the dike contain numerous fragments of granitic rock and one specimen consisted of about seventy-five per cent fragments (cf Plate 25).

Several small dikes of fine grained pyroxene andesite and a small dike of andesite porphyry also cut the granite in this vicinity. The andesite dikes have chilled borders. These dikes represent later volcanic activity than that represented by the Mt. Garfield Volcanics.

Lake Wildcat Metamorphics

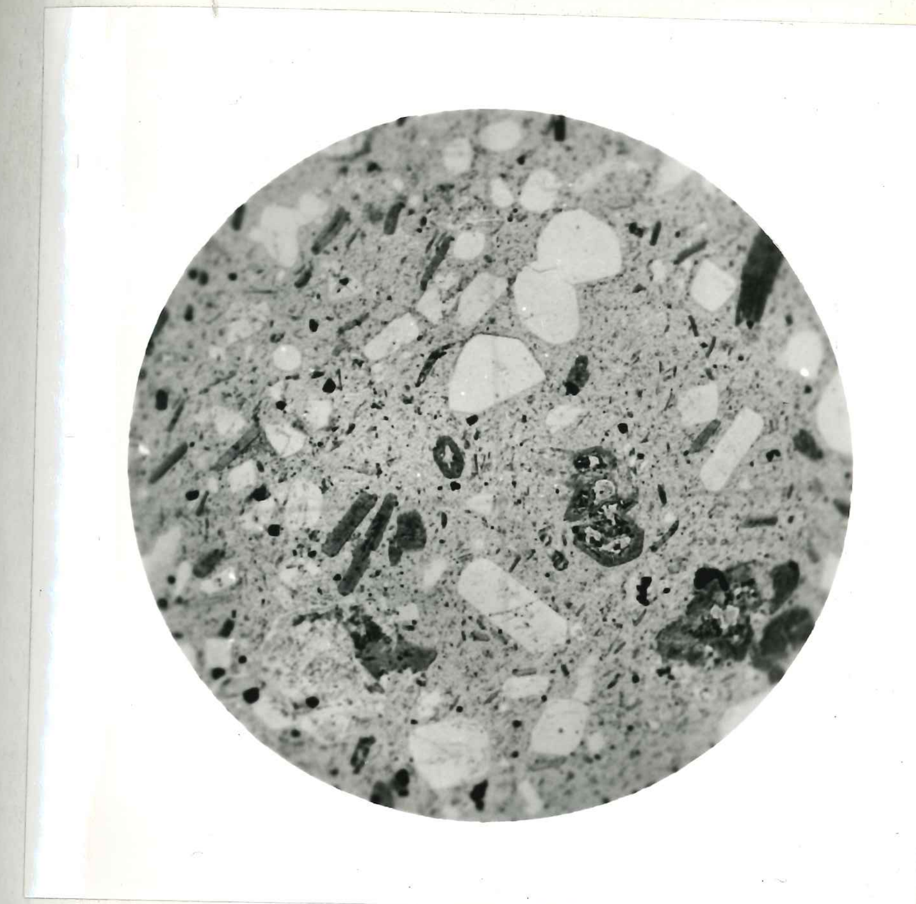
General Features

This group of rocks outcrops in the southeastern part of the map area. It includes two small areas of banded metamorphic rocks which when combined cover less than one square mile, plus some massive greenstones of which only a small amount are within the map area. One of the areas of banded rocks is south of Mt. Roosevelt and north of Lake Kaleetan, and the other is in the immediate vicinity of Lower Wildcat Lake. These rocks are relatively thin bedded pyroclastics and clastics metamorphosed to mylonitic schists and amphibolites (cf Plate 26).

PLATE 23

Photograph of a dacite dike cutting Preacher granite north of Rainy Lake. The twenty-five foot dike shows good columnar structure.

PLATE 24

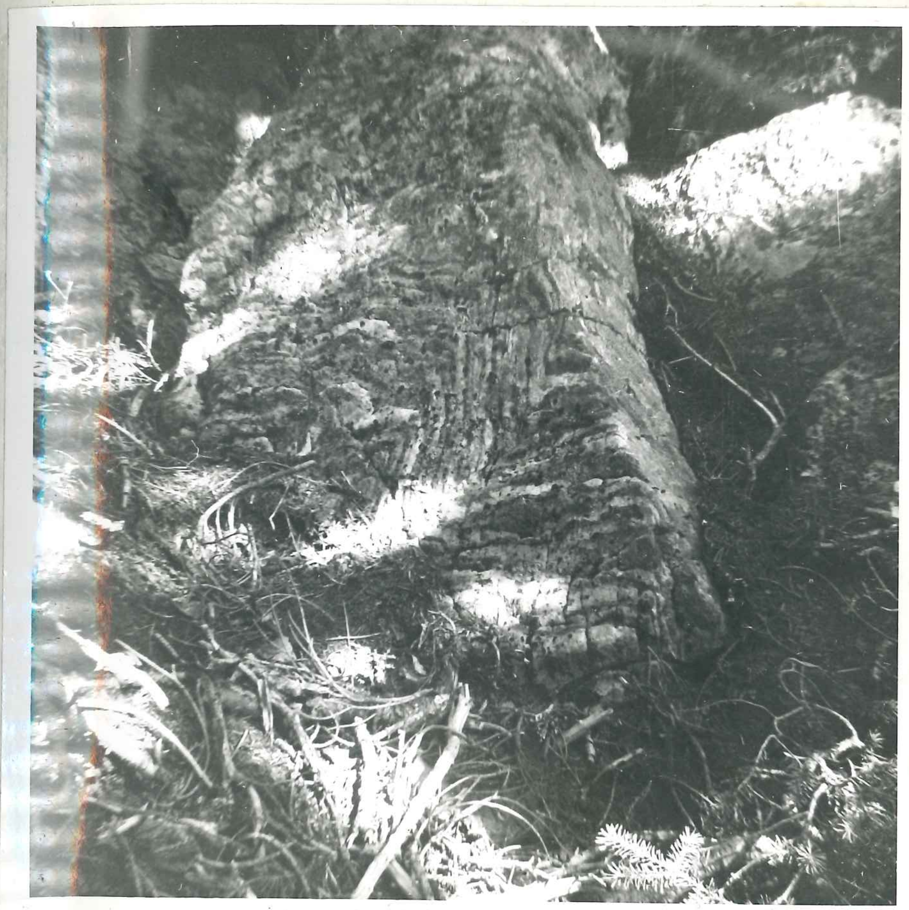


Photomicrograph of dacite from dike north of Rainy Lake (cf Plate 23), showing phenocrysts of biotite, hornblende and oligoclase and also corroded fragments of quartz and feldspar from the surrounding granite. (Plain light; x 12)

PLATE 25

Photomicrograph of a rock from near the border of a dacite dike in which fragments of granite constitute seventy-five per cent of the rock. (x-Nicols; x 12)

PLATE 26



Photograph of banded mylonitic schist of Lake Wildcat Metamorphics from outcrop southeast of Mt. Roosevelt.

The two small areas mentioned above are separated by granitic rocks of the Preacher stock, which in this border region include some microgranites. On the southeast the rocks give way to the more massive greenstones mentioned above. Between Lower Wildcat Lake and Gem Lake the greenstones can be observed in contact with microgranites and granite porphyries of the Preacher stock. The contacts are very irregular, and at one point what appears to be bedding in the greenstone is highly inclined and distorted. Due to the extreme deformation of these rocks and their irregular contact with fine grained granitic rocks it is difficult to determine the exact stratigraphic relation between the banded rocks and the massive greenstones but it seems likely that they belong together and that their relation is similar to that between the Calligan formation and the Mt. Phelps and Mt. Garfield Volcanics.

On the north and northwest these rocks and the Preacher granite are interrupted by the elongated body of granodiorite which cuts across the Preacher stock in the vicinity of Mt. Roosevelt and Upper Wildcat Lake. This contact can be observed on the ridge south of Mt. Roosevelt and also near the outlet of Lower Wildcat Lake.

Some inclusions of banded hornfels and amphibolite similar to these rocks are found within the area of Preacher granite south of Mt. Garfield, and also on the slope between the Pratt River and Rainy Lake. Some banded greenstones (cf Plate 27) resembling the darker portions of these rocks form

PLATE 27

Photomicrograph of greenstone outcropping south of Lake Blethen showing numerous veinlets of hornblende. (Plain light; x 12) small outcrops on the ridge south of Lake Blethen where they are interpreted as metamorphosed tuffaceous sediments of the Calligan formation originating at the Mt. Garfield volcanic center. Some blocks ten to twenty feet in diameter of banded greenstones also outcrop just above the CCC road on the east side of the long tongue of granodiorite which extends down from Bessemer Mountain toward the Middle Fork of the Snoqualmie River. The outcrops south of Lake Blethen and above this CCC road are shown on the map in the same color as the Lake Wildcat metamorphics. Some similar bands of amphibolite occur in the vicinity of Paradise Lake in the northeastern part of the map area within the highly metamorphosed rocks in that small area of Calligan formation surrounded by granodiorite. Thus it would appear on the basis of lithology that these rocks could be highly metamorphosed tuffaceous and clastic rocks of the Calligan formation. However, Smith and Mendenhall (7), writing of the contact relations between the Snoqualmie granodiorite and the Guye sedimentary rocks in the vicinity of Snoqualmie Pass, describe an occurrence where carbonaceous slate has become a gneissoid rock, the black layers alternating with irregular bands of quartz and feldspar. Therefore, since these rocks could have originated by metamorphism of either the Guye or Calligan formations, or even be older, it seems better to assign these rocks to a separate formation.

Petrology of the Lake Wildcat Mylonitic Schists, Amphibolites, Etcetera

All of these rocks are banded. The individual bands vary from several feet to fractions of an inch in width. Common colors are dark green, purple, black and light gray. The dark green bands are amphibolites, consisting primarily of a green amphibole, but usually with some biotite. The amphibole occurs in elongated, small grains. It is pleochroic, with Z = pale green, Y = very pale green, and X = pale yellow. The maximum extinction angle Z to c observed was sixteen degrees. Due to its fibrous habit, pale color, and moderate extinction angle the amphibole is best called actinolitic hornblende.

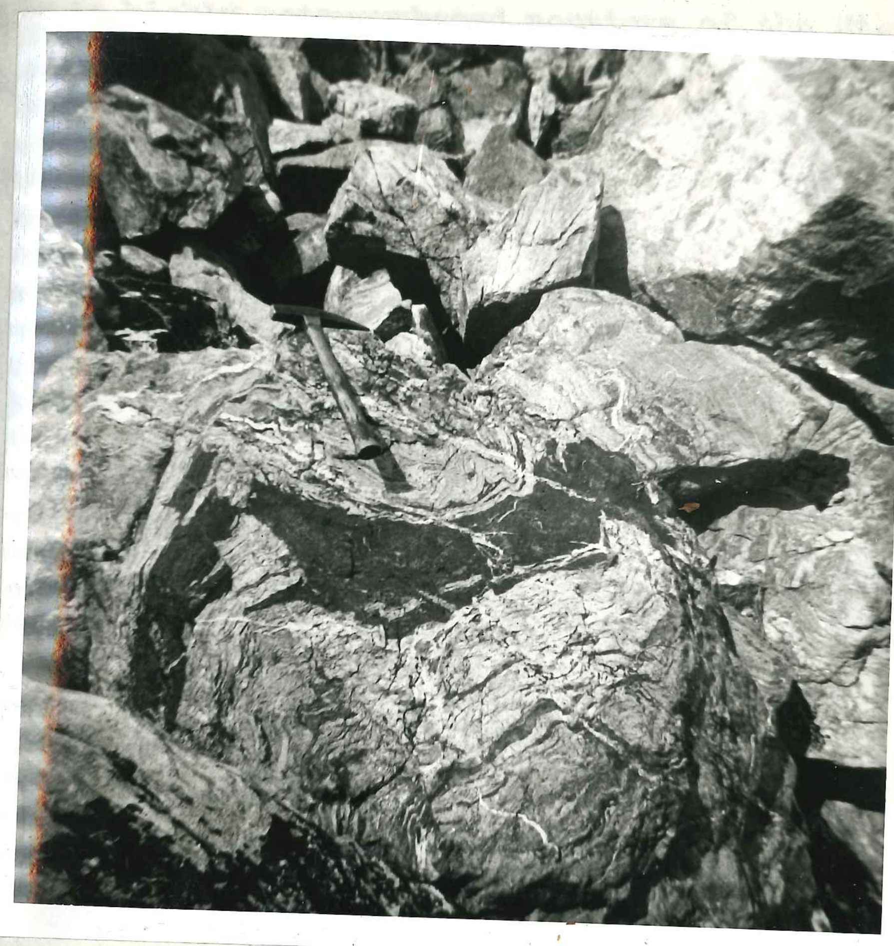
The purplish colored bands are mylonitic schists and when examined in thin section show the rock to have suffered intense shearing during which quartz separated out into bands or lenses and biotite concentrated in biotite rich bands. The rock was then recrystallized statically so that the quartz in the bands and lenses forms a mosaic texture while the remainder of the rock consists of very fine grained biotite and quartz. Magnetite is distributed throughout the rock and there is some hematite staining. Some of the lenticular shaped areas of quartz have some concentrations of biotite around their borders as further evidence of metamorphic differentiation.

The black bands are composed essentially of biotite, but there is usually some quartz and hornblende. This biotite is fine grained, partly in well formed small plates and the remainder in more irregular grains. Abundant magnetite is scattered through the biotite. In some bands the biotite and hornblende are intimately intergrown but generally they occur in separate bands. The high concentration of biotite in dark bands appears to be the result of metamorphic differentiation, rather than of biotitization of hornblendic bands of which there is no indication.

The light gray bands consist of quartz, some untwinned feldspar, and disseminated fine grained biotite, the latter giving the bands the gray color. The biotite in these gray bands is of greenish brown color rather than reddish brown as in the case of the purple colored bands. One specimen of gray and black banded mylonitic schist from the outcrop shown in the photograph in Plate 28 shows much evidence of metamorphic differentiation with quartz bands alternating with bands of greenish brown biotite, often in very fine sharp banding. Locally small veinlets of quartz extend out from the quartzose bands cutting across the biotite bands indicating solutional movement of quartz within the rock.

These metamorphic rocks have evidently formed from interbedded clastic and tuffaceous rocks. The amphibolites formed from tuffaceous rocks and the mylonitic schists formed from beds of quartzose argillites or graywackes, although the fine details of the banding are largely the result of metamorphic differentiation rather than original fine bedding.

PLATE 28



Photograph of mylonitic schist outcropping south of Upper Wildcat Lake.

The massive greenstones are dense, dark green massive rocks composed essentially of andesine feldspar and hornblende. Most of the hornblende is secondary. These greenstones are similar to highly metamorphosed portions of the Mt. Garfield Volcanics.

Subdivisions of "Snoqualmie Batholith" in Map Area

The "Snoqualmie Batholith" has long been described as one of the large granitic masses within the Cascade Range. Previous geologists who have worked on it have almost always mentioned that granodiorite predominates but that other rocks also commonly occur, including such diverse types as gabbro, pyroxene diorite, quartz diorite and granite. Most maps published do not show any boundaries of these various types. On preparing this thesis an attempt has been made to map the boundaries of the various granitic types in as great a detail as possible.

In this thesis the term "granitic rocks" is used in a broad sense and is meant to include all the granular plutonic rocks varying from quartz diorite to granite. Within the map area granodiorite has the greatest distribution among the granitic rocks, covering about forty-two square miles. It is a directionless granodiorite, consisting of andesine feldspar, orthoclase feldspar, hornblende, biotite and quartz. Extensive outcrops of similar granodiorite occur north and east of this map area. Because of local usage the name Snoqualmie granodiorite has been retained in describing this rock but in this report the term is restricted to those coarse grained facies in which the amount of plagioclase feldspar exceeds the amount of orthoclase feldspar, and not as a general term covering all the rocks in the "Snoqualmie Batholith." No detailed petrographic study of this granodiorite for the purpose of determining its genesis has been included in this thesis, but enough thin sections have been made to establish it as a mappable unit.

The next largest mass of granitic rock within the map area is a body of leucocratic granite covering about eighteen square miles in the southern part of the area, which has been called the Preacher granite. It consists primarily of orthoclase, oligoclase, quartz and biotite. In contrast to the granodiorite which normally contains twenty to twenty-five per cent hornblende plus biotite, the Preacher granite normally contains less than ten per cent mafics, and these are biotite and secondary chlorite.

Closely associated with the Preacher granite is a more heterogeneous and less easily described area of rocks occurring in the general area of Quartz Creek, which is here designated as the Quartz Creek Complex. Because of its great heterogeneity and the limited exposures in the area this complex has not been mapped in detail but has been divided into areas in which certain rock types predominate. Within the Quartz Creek Complex are an area of heterogeneous granitic rocks of migmatitic character north of Quartz Creek; an area of greenish gray tonalite in the vicinity of Mowich Lake; and an area of fine grained quartz diorite centering between Quartz Creek and the Snoqualmie River Middle Fork. The grouping of these areas together for mapping purposes is not meant to imply that all the rocks within the complex have a common genetic origin.

A very small body of biotite granite, the Sunday granite, outcrops along the North Fork of the Snoqualmie River between Philippa Creek and Sunday Creek. It consists primarily of microperthite, oligoclase, quartz and biotite. It is not conspicuous because of its limited exposures in a very heavily wooded area.

Quartz Creek Complex

General Statement

It has been mentioned earlier that the Quartz Creek Complex has been divided into an area of heterogeneous granitic rocks between Quartz Creek and Marten Lake, an area of tonalite near Mowich Lake, and an area of fine grained quartz diorite near Quartz Creek. The boundaries dividing these separate areas on the accompanying map are largely diagramatic. These rocks are similar in that they have an overall heterogeneous appearance. Although part of the rock of tonalitic composition around Mowich Lake is of fairly uniform composition it is gradational on the south into some of the darker colored rocks of the Area of Heterogeneous Granitic

Rocks. This latter area is made up of rocks varying in composition from quartz dioritic to granitic, with the rocks becoming more acidic toward the south and east.

The fine grained quartz diorites in the vicinity of Quartz Creek are of darker color and more basic in composition than the rocks of quartz dioritic composition included in the area to the north. The granite associated with the fine grained quartz diorite is the same as the Preacher granite and inclusions of quartz diorite are contained in the Preacher granite. There is also a zone of quartz diorite between the Preacher granite and the Mt. Garfield Volcanics on Mt. Garfield. The relations between the component parts of the Complex and between the Complex and the surrounding rocks will be discussed below.

Area of Heterogeneous Granitic Rocks

General Features

This area offers limited exposures and therefore the field relations are somewhat in doubt. However, where exposures are available such as along some creek beds and on the crests of some ridges the rocks exhibit many variations in texture and composition. Light gray to light brown colored rocks of granitic to granodioritic composition predominate but some darker gray fine grained rocks of quartz dioritic composition also occur. Some of these latter rocks are indistinguishable from the finer grained tonalites near Mowich Lake and thus the northern boundary of this area is gradational. The amount of the lighter colored rock increases toward the eastern part of this area and between Quartz Creek and Marten Lake, on the ridge north of the Taylor River, there are large outcrops of fine to medium grained leucocratic granitic rocks with numerous large quartz grains visible. Megascopically the rocks here somewhat resemble the Preacher granite.

A coarse conglomeratic appearing rock outcrops over an irregular shaped area about one-fourth mile in diameter along the Quartz Creek logging road above the first switch-back. On the south and east this conglomeratic rock contacts quartz diorite. North and west of the conglomerate the over-burden is deep and outcrops are few but the float is princi-pally composed of relatively leucocratic granitic rocks. This granitic conglomerate reappears a half mile to the east in a small outcrop on the north side of the Taylor River Valley. North and east of this outcrop the rocks are granitic to quartz dioritic in composition. They are exposed in the small stream canyons leading north from the Taylor River as alternate light and dark colored bands and patches with irregular grada-tional boundaries. The rocks above and to the west of this small patch of granitic conglomerate are either fine grained quartz diorites or belong to the small area of Mt. Garfield volcanics north of the Taylor River. The Area of Heterogeneous Granitic Rocks as shown on the map is arbitrarily fixed at this point to include the granitic conglomerate and the heterogeneous rocks along the Taylor River and exclude the fine grained quartz diorites and the volcanic rocks.

Some of the coarser grained gray rocks in the Area of Heterogeneous Granitic Rocks are similar to the large mass of granodiorite in the northeastern part of the map area. It is noticeable that east of Marten Lake and north of Cougar Lake the rocks are granodiorite throughout and of fairly uniform texture so the latter area is shown on the map as part of the Snoqualmie granodiorite.

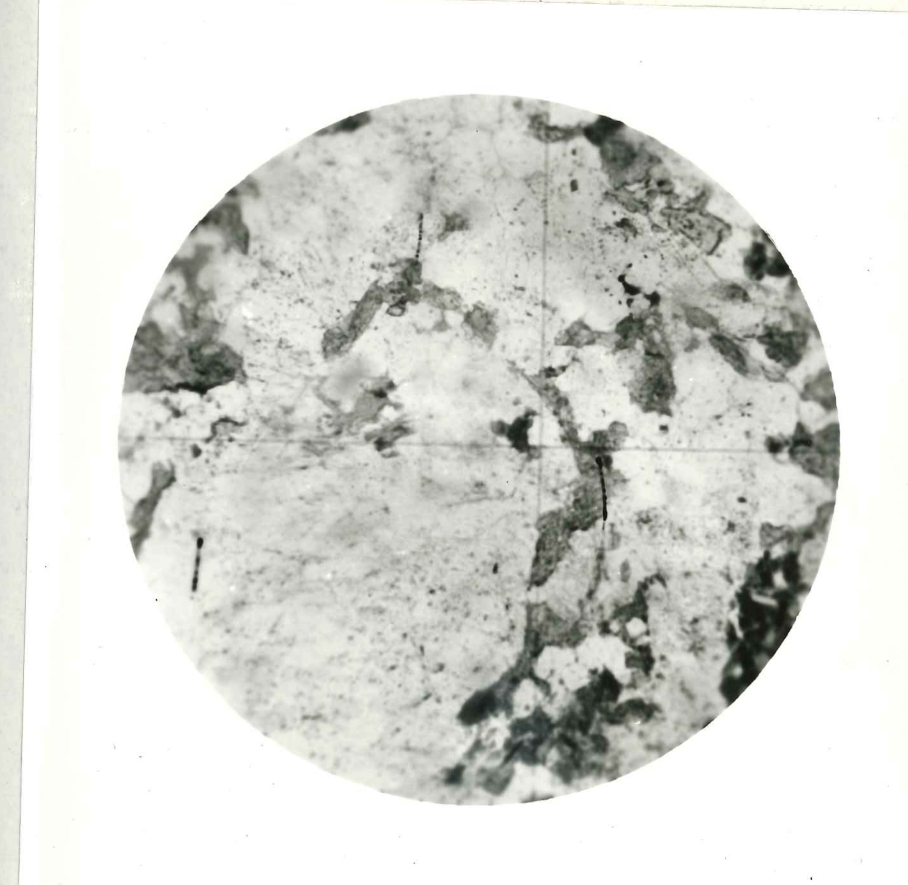
The nature of the boundary on the west will be discussed below.

Petrography

The fine grained light gray to light brown rocks near the center of the area have a crystalloblastic texture. They consist of plagioclase and orthoclase in varying proportions together with quartz, hornblende and biotite. The plagioclase varies from oligoclase in the lighter colored rocks to andesine in the darker varieties, and it usually is twinned and also zoned with a more albitic rim. The hornblende is in aggregates or in fibrous masses and appears to have grown by coalescence of numerous small grains by collective crystallization or local metamorphic differentiation. The ratio of hornblende to biotite varies widely, but in general the amount of biotite exceeds the amount of hornblende. In some cases the biotite appears to be forming by biotitization of hornblende but in most cases it appears as irregular shaped grains along the boundaries between quartz and feldspar (cf Plate 29). The plagioclase often forms grains somewhat larger than the remainder of the rock. The groundmass then usually consists of quartz, feldspar and mafics in a granulitic crystalloblastic texture (cf Plate 30).

The crystalloblastic texture of these rocks indicates that they have formed by metamorphism. Throughout most of the area the original character of the rock before recrystallization is largely obscured. However, in the western part of the Quartz Creek Complex, for example along the ridges south of Blethen Lake, there are some large outcrops of fine grained light to medium grained rocks which, on the basis of their appearance in the field, might be named microgranite or microdiorite. In thin section these rocks reveal relics of a clastic texture (cf Plate 31). The quartz grains have grown by coalescence of numerous smaller grains or locally have recrystallized into a mosaic texture. New porphyroblasts of feldspar have developed which are clearer than the original clastic feldspar. The biotite has been excluded from the areas occupied by these porphyroblasts and forms ragged grains around their borders. Comparing the microscopic features of these rocks with those of the altered massive feldspathic graywackes of the Calligan formation to the west reveals that these rocks are metamorphosed feldspathic graywackes. Recrystallization has caused these rocks to have a fresh appearance on a fracture, which combined with the growth of the larger biotite grains and

PLATE 29

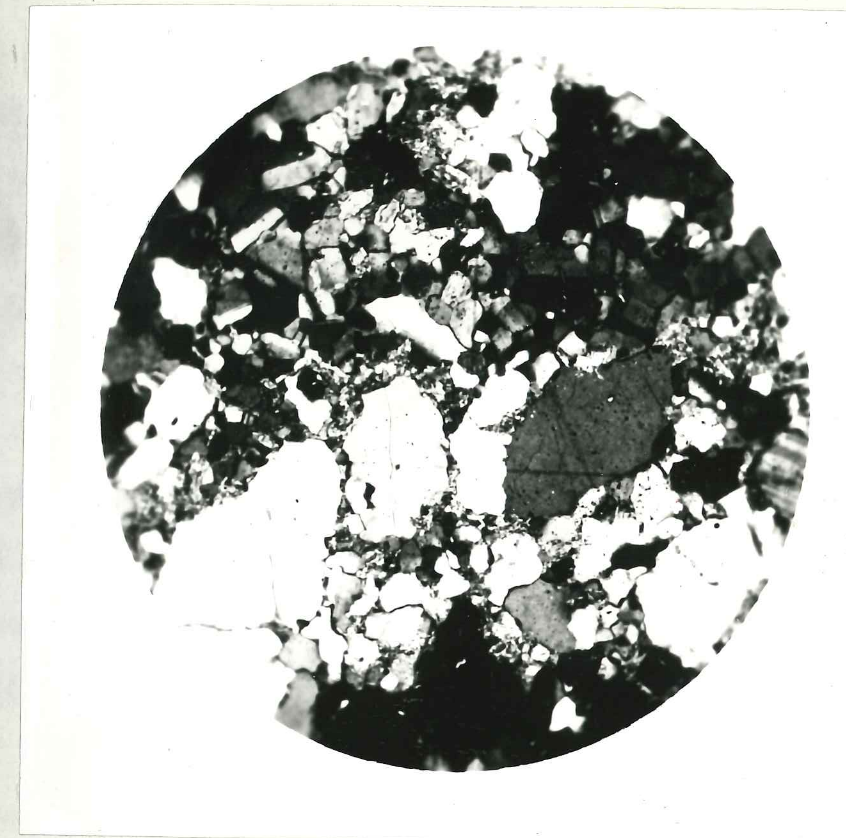


Photomicrograph of partially granitized graywacke from north of Quartz Creek in Area of Heterogeneous Granitic Rocks, showing the irregular shaped hornblende and biotite grains. (Plain light; x 40)

PLATE 30

Photomicrograph of same partially granitized graywacke as Plate 29, showing porphyroblasts of plagioclase feldspar in a granulitic groundmass. (x-Nichols; x 40)

PLATE 31



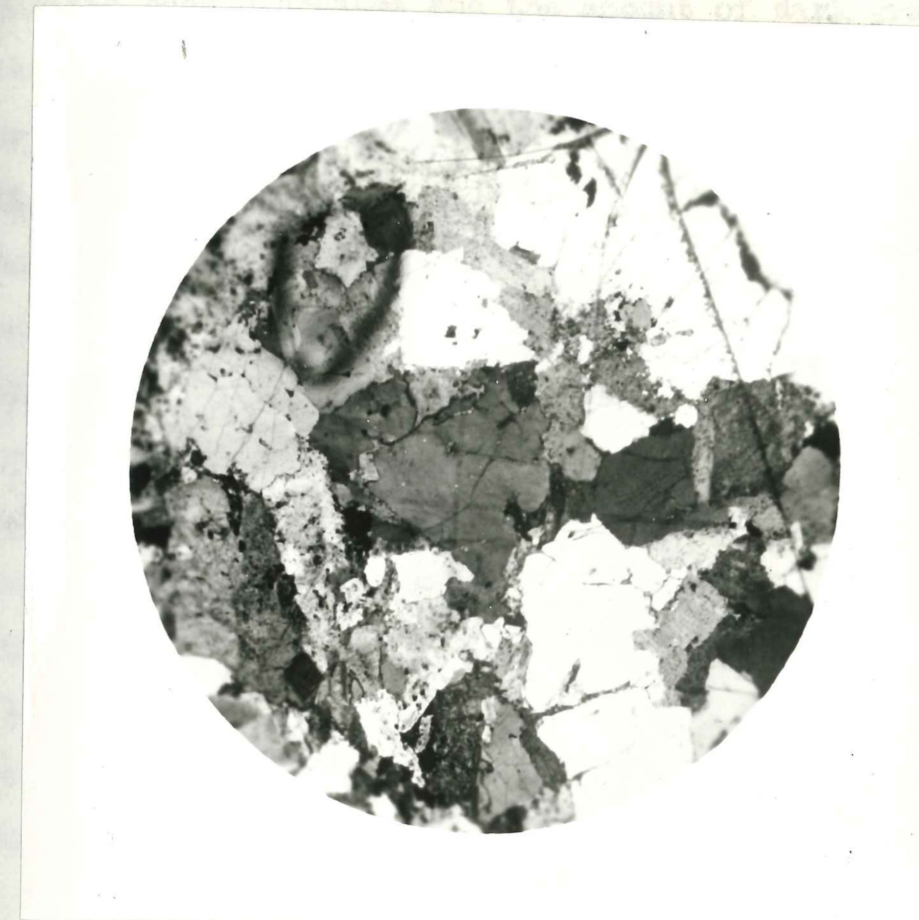
Photomicrograph of fine grained recrystallized feldspathic graywacke from ridge south of Blethen Lake (x-Nichols; x 40)

a lack of any visible structure in the hand specimen gives them a misleading igneous appearance. Granitization of somewhat similar rocks belonging to the Swauk formation near Wenatchee has been described by H. A. Coombs (3).

Some of the rocks of the Area of Heterogeneous Granitic Rocks are thus seen to be gradational into the Calligan formation to the west. In many cases the change is mostly one of recrystallization with little evidence of material being added. Since the feldspar in the feldspathic graywackes is largely plagioclase feldspar the rocks in the Area of Heterogeneous Granitic Rocks which have suffered only recrystallization are largely of quartz dioritic to granodioritic composition. The chloritic matrix of these graywackes recrystallizes to form both biotite and hornblende but biotite predominates.

In an intermediate stage of recrystallization the large quartz and plagioclase porphyroblasts become numerous and only small areas of groundmass with a granulitic texture remain (cf Plate 30). In a more advanced stage the entire rock is recrystallized to a coarse grained crystalloblastic texture (cf Plate 32). In these latter rocks there is usually considerable metasomatism with a replacement of some of the earlier plagioclase by orthoclase so that the rock has acquired the composition of a granite. This potash metasomatism is evident in the rocks north of the Taylor River between Marten Lake and Quartz Creek where some of the outcrops resemble

PLATE 32



Photomicrograph showing a medium grained granite formed by granitization of a feldspathic graywacke; from ridge between Quartz Creek and Marten Lake. (x-Nicols; x 15) parts of the Preacher granite. The north slope of the Taylor River is quite steep and descending this slope the amount of leucocratic rock decreases and the amount of dark gray melanocratic rock increases, until, as mentioned above, near the Taylor River the rocks consist of about equal amounts of dark and light colored material. An examination of thin sections of these rocks shows the darker rocks to be of dioritic composition with andesine feldspar and hornblende as the chief constituents while in the lighter colored patches the predominant minerals are oligoclase and quartz. Quartz forms irregular patches and poikiloblastic grains in the quartz diorite and makes up over fifty per cent of the lighter colored rock. Much of this quartz appears to have been introduced and in this locality it is hard to determine how much material has been added and how much originated by recrystallization of pre-existing rocks.

Mention should be made of the occurrence of a finer grained, gray rock, with numerous megascopically visible quartz grains scattered through a rather fine grained gray groundmass, which outcrops at the top of the 5340 feet high peak west of Marten Lake. In thin section this rock is seen to have a cataclastic texture in which a rock of originally granitic composition and crystalloblastic texture has been extremely brecciated, with only porphyroclasts and elongated islands of the original rock remaining in a fine grained groundmass (cf Plate 33). The quartz grains of the original rock resisted

PLATE 33

Photomicrograph of a mylonite from the peak west of Marten Lake showing porphyroclasts of an original granitic rock in a fine grained cataclastic groundmass. A small amount of biotite has developed in the groundmass. (x-Nicols; x 12) the shearing better than the other grains and predominate among the porphyroclasts, but even these show fracturing and undulating extinction.

Granitic conglomerate

This rock contains rounded pebbles up to six inches in size. Both pebbles and matrix have been recrystallized so that locally they can not be told apart and the conglomeratic appearance is more noticeable in the outcrop than in thin section. The pebbles and matrix are mostly leucocratic and fine to medium grained. However some of the pebbles contain more mafics and therefore are darker in color (cf Plate 34). There are some patches of coarse grained leucocratic granitic rock. In thin sections of the conglomerate the texture of both fragments and matrix is seen to be crystalloblastic. The rock has been severely brecciated and fractures have occurred along the curved borders of many of the pebbles and fragments (cf Plate 35). Along these fractures some chlorite and biotite often have developed. The matrix of the conglomerate is usually richer in quartz than the fragments. Much of this quartz in the matrix appears to have been hydrothermally introduced as is shown by the presence of small amounts of ore minerals with the quartz.

It is hard to explain the numerous well rounded pebbles and the diversity of fragments observed in this rock in any other way than by assuming a clastic origin. From the recrystallization of the other rocks in this vicinity it is apparent

PLATE 34

Photograph of cut surface of granitic conglomerate outcropping along Quartz Creek logging road showing rounded outlines of fragments. Two-thirds natural size.

PLATE 35

Photomicrograph of the border of one of the rounded granitic pebbles in granitic conglomerate from Quartz Creek logging road showing the curved fracture around the border of one pebble. (x-Nicols; x 12) that most of the original microscopic features of a small mass of conglomerate such as this would be altered by the recrystallization, although the overall conglomeratic appearance could still be preserved.

Tonalite Near Mowich Lake

General features

In the vicinity of Mowich Lake, near the headwaters of Sunday Creek, and south of this lake along the divide between Quartz Creek and the Sunday Creek drainage areas is an area of tonalite. In the vicinity of Mowich Lake it is a gray medium grained rock with sometimes a faint tinge of green. Both feldspar and quartz grains are visible in the hand specimen. The mafics, consisting of hornblende and biotite, appear quite black, and have a tendency to occur in groups one-eighth to one-fourth inch in diameter. It is not as leucocratic as the large masses of granodiorite to the north of it and does not have as fresh an appearance or as uniform a texture.

The abrupt change from tonalite to granodiorite along the ridge between the Quartz Creek and Sunday Creek drainage areas directly south of Sunday Lake can be readily observed. This contact can also be noted north of Mowich Lake by a change in the type of talus west of the creek draining the lake. As the tonalite is followed to the south from Mowich Lake it decreases in grain size. This decrease can be noted when climbing up the Quartz Creek trail from Mowich Lake, at

3200 feet elevation, to the divide at 4000 feet elevation. The southern limit of the area of tonalite is arbitrary since the finer grained tonalite is indistinguishable from some of the darker colored rocks in the Area of Heterogeneous Granitic Rocks. The tonalite differs from the fine grained quartz diorites to the south in being somewhat lighter colored and it does not have the fresh appearance of these quartz diorites. The abundance of biotite in the tonalites and its scarcity in the fine grained quartz diorites is another distinguishing feature. Some outcrops of fine grained gray rock similar to the tonalite occur in the Area of Fine Grained Quartz Diorite also; so the division of the Quartz Creek Complex into the three areas given on the map is merely diagramatic and the distribution of rock types has numerous irregularities which are not shown.

Petrography

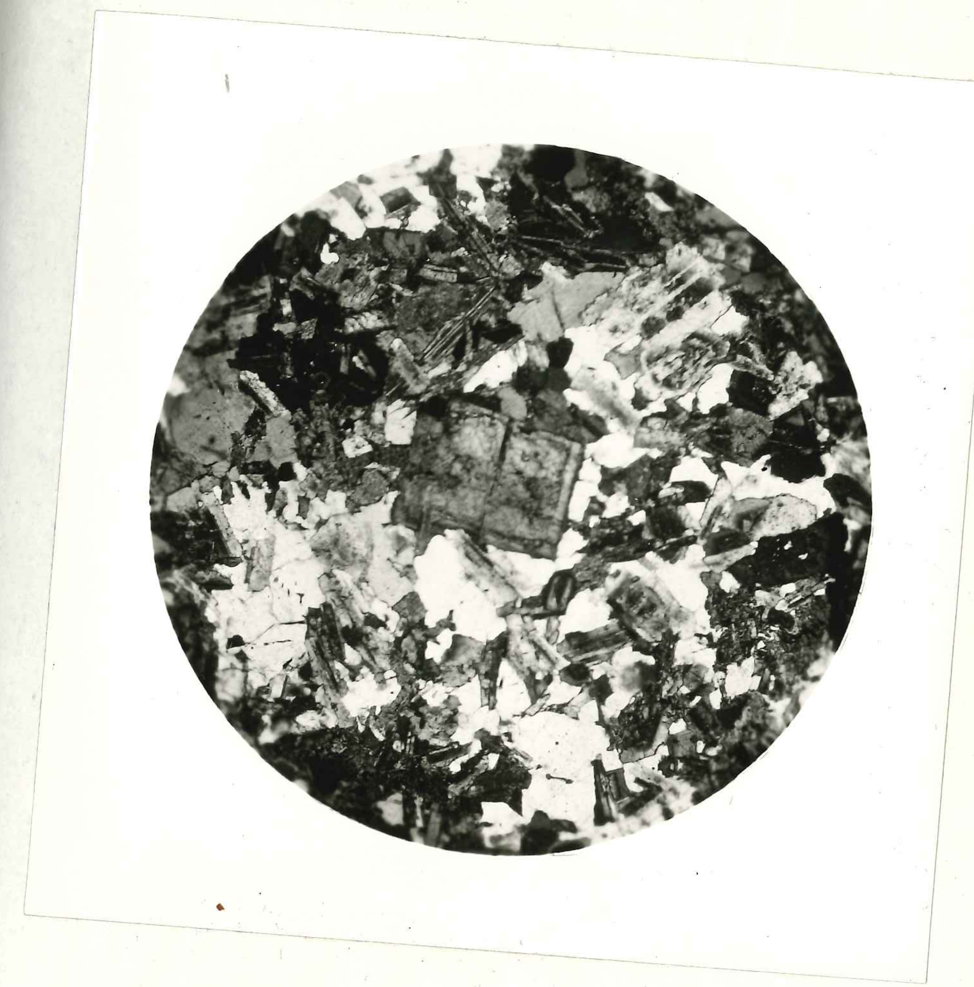
Although the grain size of some of the coarser grained tonalite near Mowich Lake approaches that of the normal granodiorite to the northeast the rock is seen in thin section to be closer to a tonalite than to a granodiorite as only about five per cent of orthoclase is present. The plagioclase feldspar is andesine (averaging $An_{35}Ab_{65}$) and comprises over fifty per cent of the rock. It occurs in subhedral crystals, one to two millimeters in size, and is usually zoned and free from alteration. Some of the plagioclase has a light greenish tinge in the hand specimen. The quartz comprises about twenty per cent of the rock and is mostly intergranular. A few larger grains of quartz are poikiloblastic and inclose earlier plagioclase (cf Plate 36). The hornblende and biotite are mostly anhedral and occur partly in small groups or segregations, one-eighth to one-fourth inch in diameter, producing a somewhat "glomeroporphyritic" texture. The amount of biotite usually exceeds the amount of hornblende. Some of the biotite follows the boundaries between grains of quartz and feldspar and even seems to penetrate along some cleavage cracks in the plagioclase (cf Plate 37). The overall texture is crystalloblastic. There is insufficient petrographic evidence in the specimens studied to reach any definite conclusions regarding the genesis of the tonalite. The poikiloblastic grains of quartz, the overall crystalloblastic texture, and the irregular nature of the biotite and hornblende suggest that it is a basic rock which has suffered considerable recrystallization and metasomatism but the nature of the original rock is unknown.

The Area of Fine Grained Quartz Diorites

General Features

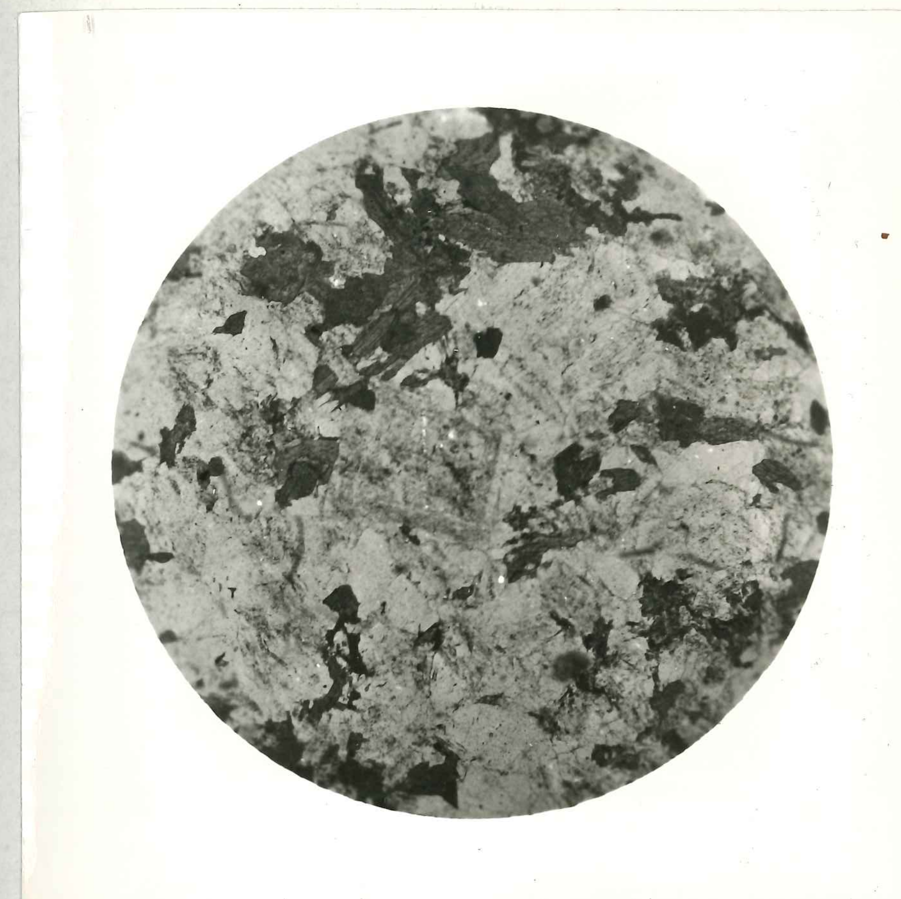
These rocks are dark gray or dark greenish gray and of fine to medium grain size. They have andesine feldspar, hornblende, and quartz as the principal constituents. From outcrop to outcrop they show numerous variations in grain size and in the percentage of feldspar, quartz, and mafics. Some of the finer grained quartz diorites can not be told megascopically

PLATE 36



Photomicrograph of fine grained tonalite outcropping
tween Quartz Creek and Mowich Lake. A large poikiloblastic
ain of quartz incloses an euhedral plagioclase crystal and
so other smaller grains. (x-Nicols; x 15) Plate 37 shows
e same thin section in plain light.

PLATE 37



Photomicrograph of same thin section as shown in Plate 36. (Plain light; x 15) The hornblende and biotite form irregular grains penetrating along the boundaries between quartz and feldspar.

from the Mt. Garfield andesites.

Some of the quartz diorites are uniformly fine grained with a fresh appearance on a newly fractured surface. This type is especially numerous around the northern border of the Preacher granite and as inclusions within it, some of which measure as much as one hundred feet across. Locally these fine grained quartz diorites contain very irregular shaped patches of more leucocratic rock and then they have the appearance of migmatites. These migmatites are well exposed in the vicinity of Nordrum Lookout near the mouth of the Taylor River.

The more leucocratic quartz diorites, as well as forming patches in some of the fine grained quartz diorites, locally also occur in fairly large masses. These leucocratic quartz diorites are usually adjacent to Preacher granite and also occur as inclusions in the granite. They have large grains of andesine feldspar in a groundmass which is darker in color and sometimes resembles the quartz diorites described in the previous paragraph, but often is even finer grained.

Other outcrops of quartz diorite have a streaky appearance due to the growth of biotite and hornblende along fractures. Some of these rocks contain forty to fifty per cent hornblende and are so dark in color as to be told with difficulty from the Mt. Garfield andesites without a microscope. They are especially numerous adjacent to these volcanics north of Quartz Creek.

Specific occurrences of the various types of quartz diorites will be discussed in detail below, together with their petrographic details. Good exposures of quartz diorites are present along the St. Regis logging road on the north side of Quartz Creek. These rocks vary considerably in texture and have some areas of granite ten to twenty-five feet wide in them. They are cut by numerous faults striking N65°W to N90°W and the outcrops of granite are bounded by faults. One large outcrop exposed in a rock slide reveals rounded inclusions of dark colored fine grained quartz diorite in a coarser grained more leucocratic quartz diorite and is similar in appearance to some outcrops in the migmatitic border of the Snoqualmie granodiorite along the Lennox River (cf Plate 52).

Quartz diorites outcrop in irregular fashion along the northwest edge of the Preacher granite. At most places the transition from granite to quartz diorite is fairly abrupt, often with visible cataclastic textures. There is no tendency for a belted appearance of the outcrops here, but rather the traces of the contacts between sediments and diorites and between diorites and granite are very irregular. Along the CCC road just within the edge of the Calligan formation as shown on the map are two large outcrops about fifty feet wide of porphyritic rock with visible phenocrysts of feldspar in a dark colored aphanitic groundmass. A study of thin sections of the rocks shows them to be andesite porphyry, somewhat finer grained along the borders. The groundmass contains much hornblende and no quartz. These rocks can not be traced in the heavy timber beyond the road cut but the contacts of the andesite porphyry with the highly disturbed Calligan graywackes and argillites appears to be in an approximate east-west direction across the strike of any bedding that can be recognized in the vicinity so it is possible that they are dike-like masses. These andesite porphyries megascopically resemble some of the finer grained quartz diorites. Contact relations in this vicinity are further complicated by faulting in an east-west direction. Immediately north of the CCC road the quartz diorites contact hornfelses and granulites of the Calligan formation while farther to the north they are in contact with dark greenish metamorphosed tuffaceous rocks rich in hornblende. The quartz diorites display here the same wide variety of textures as in the vicinity of Quartz Creek. One large outcrop resembles the finer grained tonalites south of Mowich Lake and it is possible that these quartz diorites are of more than one age and genesis.

Petrography

Fine grained quartz diorites associated with Preacher granite. The fine grained fresh appearing quartz diorites are everywhere closely associated with the Preacher granite and it is hard to discuss the two rock types entirely separately. Outcrops of the dark gray, even grained quartz diorite are numerous on the slope north and northwest of Nordrum Lookout, between the Middle Fork of the Snoqualmie River and Quartz

Creek. The outcrops in the timber are about equally divided between quartz diorite and granite, including locally some fine grained microgranite. One outcrop of granite contains several round areas up to six feet in diameter of fine grained quartz diorite with very sharp boundaries, while a few hundred yards away the quartz dioritic inclusions are elongated in an east-west direction. One large outcrop forming a low cliff consists of ninety per cent fine grained quartz diorite with ten per cent of irregular shaped patches of coarse grained more leucocratic rock.

The fine grained quartz diorite in the outcrops mentioned above consist of lath shaped grains of andesine feldspar and irregular shaped grains of green hornblende. The most distinctive feature of the feldspars is the absence of alteration products which accounts for the fresh appearance of these rocks. Some interstitial quartz is present and the amount varies from ten to twenty-five per cent. The hornblende has a crystalloblastic texture with irregular outlines and varies in amount from twenty to forty-five per cent of the rock. Biotite may be entirely absent or present in amounts less than five per cent and it appears to have formed by biotitization of the hornblende.

Where light colored patches occur in the fine grained quartz diorite they are composed mainly of large subhedral grains of andesine feldspar and irregular grains of quartz. Whereas the andesine feldspar in the fine grained quartz diorite is basic, approaching labradorite, that in the leucocratic patches approaches oligoclase. The borders of the large feldspars are straight and the grains are mostly free of inclusions. Locally the larger quartz grains contain inclusions of lath shaped feldspars. The hornblende in the light colored patches forms irregular aggregates and has been largely replaced by biotite. There is no potash feldspar.

Near the borders of the Mt. Garfield andesites there are numerous rocks which are intermediate between andesite and quartz diorite. In some of these rocks the original phenocrysts of plagioclase are still visible although partly altered, and small crystalloblastic plagioclase and quartz grains are developing in the groundmass of the andesite. These rocks usually do not show much recrystallization and take on the fresh appearance of the fine grained quartz diorites unless there has been an appreciable metasomatic addition of quartz. The beginnings of some crystalloblastic growth of feldspar can be seen in the groundmass of the coarse grained andesite porphyry illustrated in Plate 20.

Textures such as those in the fine grained quartz diorites thus might have resulted from recrystallization of basic rocks. The fact that the hornblende in the leucocratic patches is being biotitized and the presence of some inclusions of feldspar in the larger quartz grains suggests that these patches are due to the action of solutions containing potash and silica.

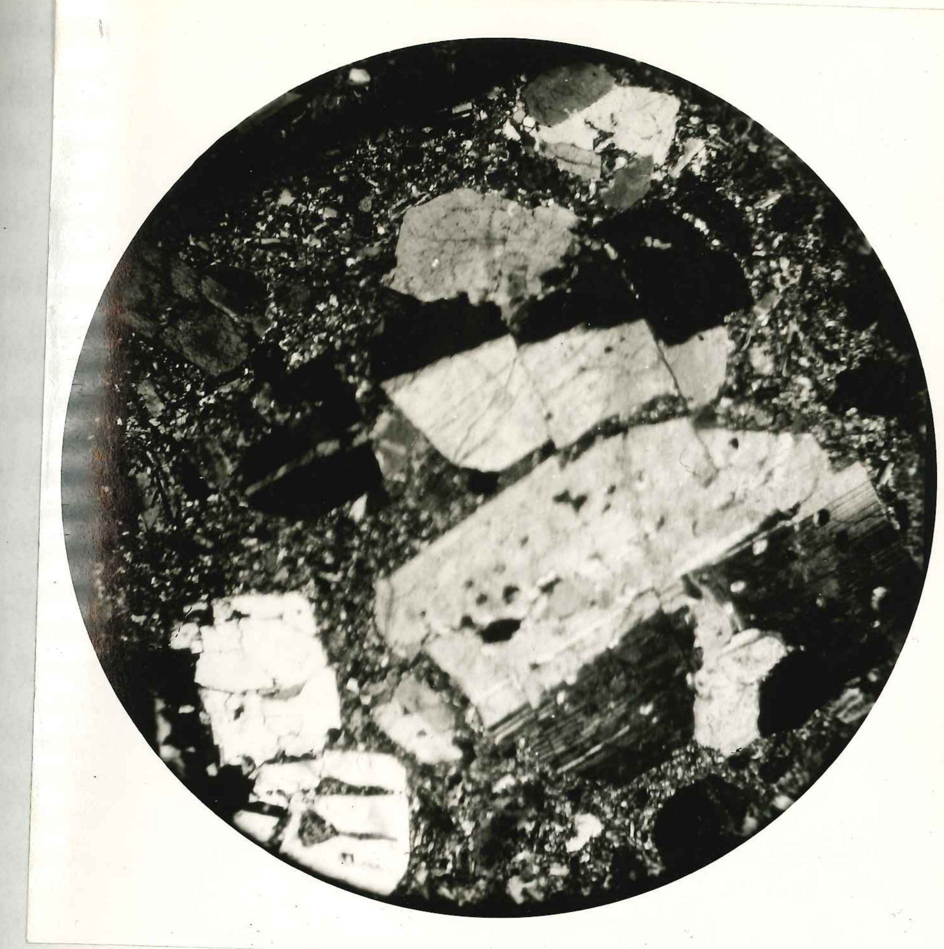
<u>Variations in textures in the vicinity of Quartz Creek</u>. The presence within the quartz diorite along the Quartz Creek logging road of some outcrops of granite bounded by faults has been mentioned above. For about ten feet adjacent to the fault the quartz diorite consists of numerous large grains of sodic andesine and quartz in a fine grained groundmass. Many of the large feldspar grains show evidence of having been fractured and rehealed with feldspar of a different orientation indicating that fracturing and recrystallization have occurred simultaneously. Some of the larger grains are composite and appear to be porphyroclasts of Preacher granite. The groundmass appears somewhat cataclastic but the fragments have been recrystallized and there has been a development of some porphyroblasts of hornblende and some veinlets of hornblende so that the rock has a marked crystalloblastic texture. There are scattered grains and irregular shaped patches of quartz in the groundmass. Beyond this ten foot zone the quartz diorite is fine grained with lath shaped andesine grains, subhedral green hornblende, and a small amount of interstitial quartz.

Farther to the north along the road there are some small angular blocks of granite a few inches across contained in fine grained streaky appearing quartz diorite. Large thin sections of these blocks show them to be typical coarse grained granite highly fractured. The fine grained rock enclosing the block consists of anhedral to subhedral crystals of andesine feldspar, quartz, and hornblende, about one millimeter in size, contained in a finer grained groundmass averaging about 0.2 millimeters in grain size. The groundmass looks cataclastic and the larger grains appear to be developing both as recrystallized porphyroclasts and as porphyroblasts (cf Plate 38). The large grains in this quartz diorite are much clearer than the grains of the granite and have crenulated borders and some contain inclusions of the groundmass. Some hornblende is growing along fractures. These occurrences of granite surrounded by quartz diorite appear to be blocks of granite which have been involved in faulting, and the brecciated granite and quartz diorite then recrystallized with some solutional interchange of material.

<u>The Quartz Dioritic Border of Preacher granite on Mt. Garfield</u>. The southeastern part of Mt. Garfield consists of Preacher granite, and the northwestern part is composed of the Mt. Garfield Volcanics. Fine grained quartz diorite outcrops between the granite and the andesitic rocks and can be examined on both the southeast and southwest slopes of the mountain.

To reach the southeastern outcrops of quartz diorite one can follow the old logging grade up the Middle Fork of the Snoqualmie River to about four miles above the Taylor River, and then climb up to the north along the timbered slope between Garfield Mountain and Dingford Creek, sometimes called Green Ridge. As stated above, the quartz diorite here is in

PLATE 38



Photomicrograph of fine grained quartz diorite from near faulted block of Preacher granite north of Quartz Creek road. Parts of the fine grained groundmass show the development of small lath shaped feldspar grains. (x-Nicols; x 15) contact with the Preacher granite. In this vicinity the latter comprises both fine grained granophyric and coarse grained varieties, and there is no appreciable change in the Preacher granite as one approaches the volcanic rocks until within less than 1000 feet of the contact. Here, at about 5000 feet elevation on the south-east side of Mt. Garfield, just above a small pond, there is an outcrop and talus slope showing a leucocratic rock slightly darker than the granite, which contains numerous inclusions of fine grained dioritic material varying from dark gray, fine grained inclusions, to skialiths visible only as darker shadows in the coarse grained rock. Going north the percentage of the darker material increases until the rock is almost entirely dioritic and fine grained, and then this rock contacts andesite breccias. This contact can be followed to the west in a fairly straight line with the rock on the north changing from andesite breccia to a rather friable porphyritic andesite, with no noticeable change in the character of the diorite on the south.

The fine grained diorite near the volcanic contact consists of fifty per cent plagioclase ($An_{50}Ab_{50}$), forty per cent brownish green hornblende, and ten per cent quartz, all in an equigranular fabric averaging about 0.3 millimeters in size. The plagioclase forms randomly oriented elongate grains and some show fairly sharp boundaries against hornblende. The amphibole is mostly brownish green hornblende in irregular grains, but some more fibrous amphibole is present which is probably secondary. The quartz is in small irregular grains between the feldspar and hornblende. The grain size of the inclusions is considerably coarser than the groundmass of the surrounding leucocratic rock, although the abundant large porphyroblasts in the latter give it a much coarser grained appearance.

The more leucocratic portion of the quartz diorite mass nearer the granitic rock is composed of about fifty per cent large grains, ranging in size from one to two millimeters, of quartz and plagioclase ($An_{28}Ab_{72}$), and fifty per cent of a finely granular groundmass averaging 0.1 millimeter in grain size. Some of the large grains are composite. A few grains show undulating extinction. A number of the large feldspar grains show one or two straight borders but mostly the crystal outlines are irregular and the borders of the crystals crenulated. The groundmass of this leucocratic quartz diorite consists of a fine grained granular aggregate of quartz, feldspar, and mafics. It looks cataclastic and incompletely recrystallized. Most of the quartz has undulating extinction. There are a few larger quartz grains which appear to have grown by coalescing of numerous smaller grains. There is a considerable quantity of epidote, and fibrous bluish green amphibole, and also some chlorite and some irregular aggregates of biotite are scattered through the rock. Well formed green hornblende is limited to the dioritic inclusions. Some large feldspar grains contain numerous inclusions of the groundmass minerals and under plain light these grains can not be told from the groundmass. The overall texture and composition of this leucocratic quartz diorite suggest that it resulted from the brecciation and recrystallization of a more basic rock with the metasomatic addition of some silica and potash.

On the southwest side of Mt. Garfield the quartz diorite again forms a border to the granite. Here, on the slope above the Taylor River forest camp, the quartz diorite makes contact with some dark colored fine grained argillites which pass westward within a few hundred yards into tuffaceous rocks. The argillites have been recrystallized into a fine grained mosaic of quartz and feldspar but some carbonaceous material is still present and the argillites are quite friable. The immediate contact between the quartz diorite and the argillites appears to be a fault at which the rocks have subsequently been indurated. The contact strikes N61°E and follows the course of a small stream flowing down over bare rocks on the south slope of Mt. Garfield before disappearing under loose rock at 1500 feet elevation. Within two feet of the contact the quartz diorite is dark gray and very fine grained, and under the microscope it appears porphyritic with larger grains of plagioclase, hornblende and augite in a fine-grained groundmass. The groundmass appears somewhat cataclastic, and some of the plagioclase crystals have been corroded and fractured and then undergone further growth, leading to the formation of much fresher appearing feldspar.

Some of the quartz diorite containing augite near the contact has an igneous appearing texture but the later growth following the fracturing appears to be crystalloblastic. The weakly metamorphosed character of the argillite a few feet from the contact indicates the absence of excessive heat during or after the faulting up of the quartz diorite.

Going south from this contact toward the granite the quartz diorite becomes quite coarse grained and somewhat leucocratic. Several hundred yards from the contact it contains some round areas thirty feet in diameter of granite, and finally a little farther south the leucocratic quartz diorite is rather abruptly succeeded by granite along a fault line striking N62°E. This fault which is parallel to the border fault further illustrates the faulting which accompanied the upward movement of the granitic body.

The contact between quartz diorite and argillite on the southwest side of Mt. Garfield is clearly a fault contact and the cross-cutting nature of the andesite-quartz diorite contact on the southeast side of the mountain suggests that this too is a fault contact. From the petrographic details described above it might be postulated that the leucocratic quartz dioritic border of the Preacher granite at this locality represents basic rocks which have been partially granitized. This material appears to have moved up principally by faulting, but whether its emplacement has been entirely mechanical is uncertain. The cataclastic textures present in parts of the leucocratic quartz diorite and the fact that on the southeast side of the mountain its groundmass is finer grained than the inclusions of more basic diorite suggests that there was considerable movement within the leucocratic quartz diorite itself as well as at the border faults.

While rocks transitional between quartz diorite and volcanic rocks are present to the north in the vicinity of Quartz Creek, such rocks are missing here due to the fact that the Preacher granite and migmatitic quartz diorite here are faulted up against relatively slightly altered volcanic rocks.

Preacher Granite

General Features

The Preacher granite is a stock-like mass, named after Preacher Mountain which is one of the most striking topographical features within the mass, and covers an area of about eighteen square miles in the southeastern part of the map area. It shows a close association of leucocratic granite and quartz diorite and some mixed rocks intermediate between the two main types.

The granitic rocks which make up the bulk of the Preacher granite are not of as uniform a composition or texture as the Snoqualmie granodiorite (restricted, cf above) but these rocks form a very distinctive and easily recognizable unit in that they are all rich in quartz and have a light color ranging from white to light gray or light brown. The predominant minerals are quartz, potash feldspar, usually in the form of microperthite, oligoclase, and usually a few flakes of biotite. The textures vary somewhat from outcrop to outcrop and for descriptive purposes the granitic rocks can be divided into several varieties which grade into each other. These are: first, fine grained microgranites and granite porphyries; second, coarse grained granite in which all the constituents are megascopically visible; and, third, a granophyric variety of granite in which micropegmatite makes up an important part of the rock. In addition to these groups there are some sugary aplites and narrow pegmatitic veins.

The distribution of the varieties of Preacher granite is not known in complete detail. Fine grained microgranites and granite porphyries occur near the borders of the Preacher granite. They do not form anything like a complete ring around the granite mass but rather form irregular shaped bodies which appear to be earlier than the coarser grained varieties. These finer grained rocks are numerous north of the Snoqualmie Middle Fork and they are similar to some rocks which have been described from the Quartz Creek Complex. Locally these microgranites are crossed by some coarse grained pegmatite veins. Between Lower Wildcat Lake and Gem Lake at the southern border of the Preacher granite are large outcrops of granite porphyries and microgranites which contact the highly disturbed greenstones of the Lake Wildcat Metamorphics. Here also the coarse grained

Preacher granite locally contains irregular shaped inclusions of these microgranites and some of these finer grained rocks have veinlets and patches of coarser grained and more leucocratic granite. If outcrops were more numerous a more complete gradation might be observed.

The southwest boundary of the granite appears to follow the course of the lower Pratt River, as granodiorite outcrops southwest of the river and the Preacher granite northeast of the river. In the vicinity of Lake Caroline the granite is interrupted by a mile wide area of granodiorite, but the granite outcrops again south of this granodiorite in the vicinity of the Wildcat Lakes.

Within the main body of the granite are found a few inclusions of greenstone and mylonitic schist and also some inclusions of quartz diorite which become more numerous as the Quartz Creek Complex is approached.

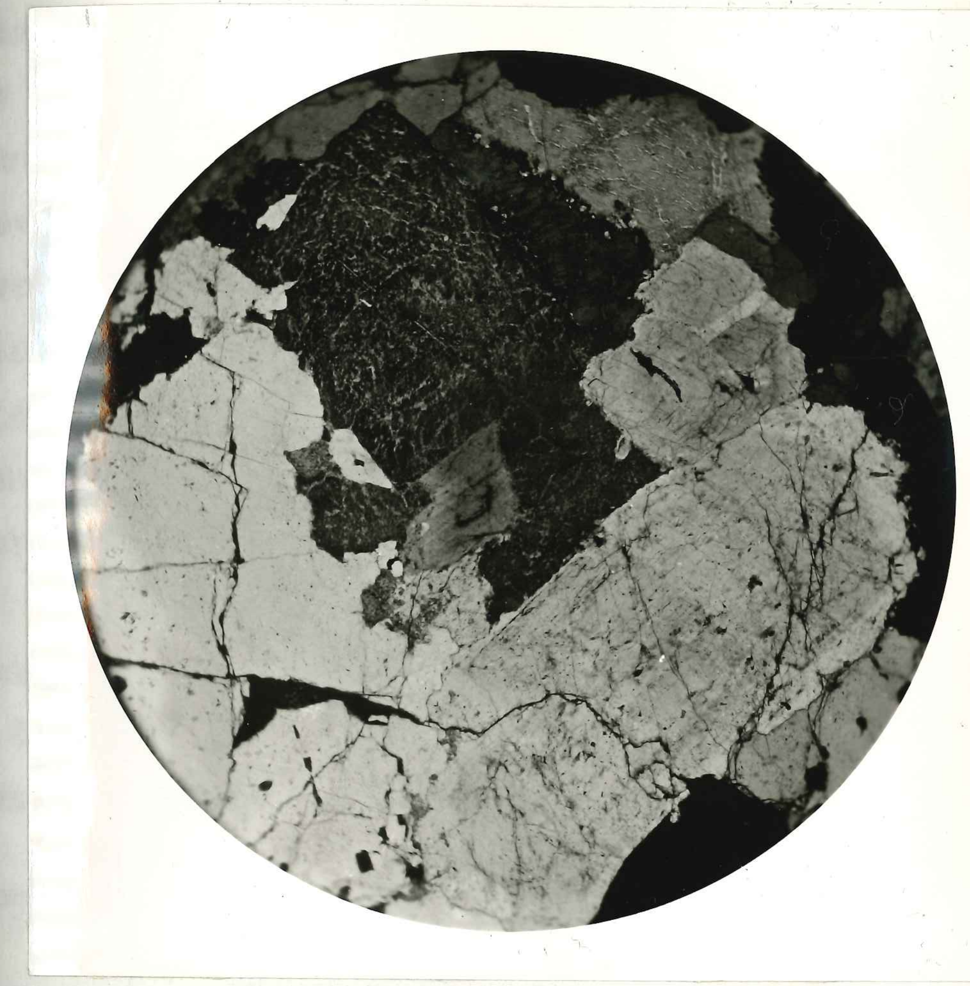
The faulting on Mt. Garfield between the Preacher granite with its quartz dioritic border and the Mt. Garfield andesites noted earlier appears to be a line of major movement, extending from Mt. Garfield southwesterly along the south side of the Middle Fork of the Snoqualmie River. South of this fault in the up thrown block the Preacher granite is relatively free of quartz diorite inclusions while north of this line the Preacher granite has an irregular distribution intimately associated with quartz diorite.

Petrography

Coarse grained granite

The coarse grained Preacher granite which is the most abundant variety is a leucocratic rock in which quartz, feldspar and usually a few flakes of biotite are visible to the naked eye. The large rounded quartz grains resist weathering and often stand out sharply on weathered surfaces. Thin sections reveal an average composition of about forty per cent quartz, thirty per cent potash feldspar, mostly in the form of microperthite, twenty-five per cent oligoclase, and five per cent mafics. The quartz occurs in large irregular shaped grains, often cracked and partly penetrated by orthoclase, and also sometimes in rather coarse inter-growths with orthoclase. The plagioclase is generally zoned, with oligoclase in the center and with a more albitic rim. It occasionally forms subhedral grains surrounded by orthoclase and quartz but usually the oligoclase is ragged and seems to have been partly replaced by orthoclase (cf Plate 39). The orthoclase is usually turbid. The most prevalent mafic is biotite in fairly large ragged plates. It is highly pleochroic, pale brown to very dark brown, almost opaque with the vibrations of the lower nicol parallel to the cleavage. The biotite is partly altered to chlorite and some magnetite is often present. Locally the Preacher granite contains some small veins of magnetite. The ratio of orthoclase to plagioclase shown above would classify

PLATE 39



Photomicrograph showing a specimen of typical coarse grained Preacher granite. A relic of plagioclase is contained in a grain of microperthite. (x-Nicols; x 15) this rock as a quartz monzonite, but since this ratio frequently varies within a small distance it will be more convenient to use the word granite to comprise all the rocks in this group; with the realization that an individual specimen may be actually a granite, quartz monzonite, or even a granodiorite depending on the orthoclase-plagioclase ratio in that specimen. This will help in subsequent discussions by differentiating these rocks from the rocks within the map area which are mapped as granodiorite in which the plagioclase feldspar definitely predominates. In thin sections of the granites, relatively less coarse grained areas of granoblastic quartz or quartz-feldspar mosaics are commonly seen.

The texture of the coarse grained granite is crystalloblastic. The origin of this crystalloblastic texture will be discussed later following the descriptions of the microgranites and granite porphyries.

Granite porphyry and microgranite

These rocks present a variety of textures and compositions. Some granite porphyry outcropping north of Nordrum Lookout near some fine grained quartz diorite is a nearly white rock with some large grains of quartz and feldspar in a fine grained groundmass. In thin section the rock shows large grains of oligoclase and quartz in a fine grained groundmass composed of quartz, orthoclase, and oligoclase in nearly equigranular anhedral grains forming a fine grained mosaic. The large plagioclase and quartz grains have crenulated borders and appear to be developing as porphyroblasts in the fine grained granular groundmass (cf Plate 40). The texture of the groundmass is similar to the texture of the granulites to the west formed by metamorphism of feldspathic graywackes of the Calligan formation. This alteration of the granulites to a more granitic appearing rock has been described earlier as occurring in the Area of Heterogeneous Granitic Rocks. However, in that instance the change was mainly one of recrystallization while in this rock in the vicinity of Nordrum Lookout there has been a great deal of potash metasomatism with the clastic derived oligoclase being partially replaced by orthoclase.

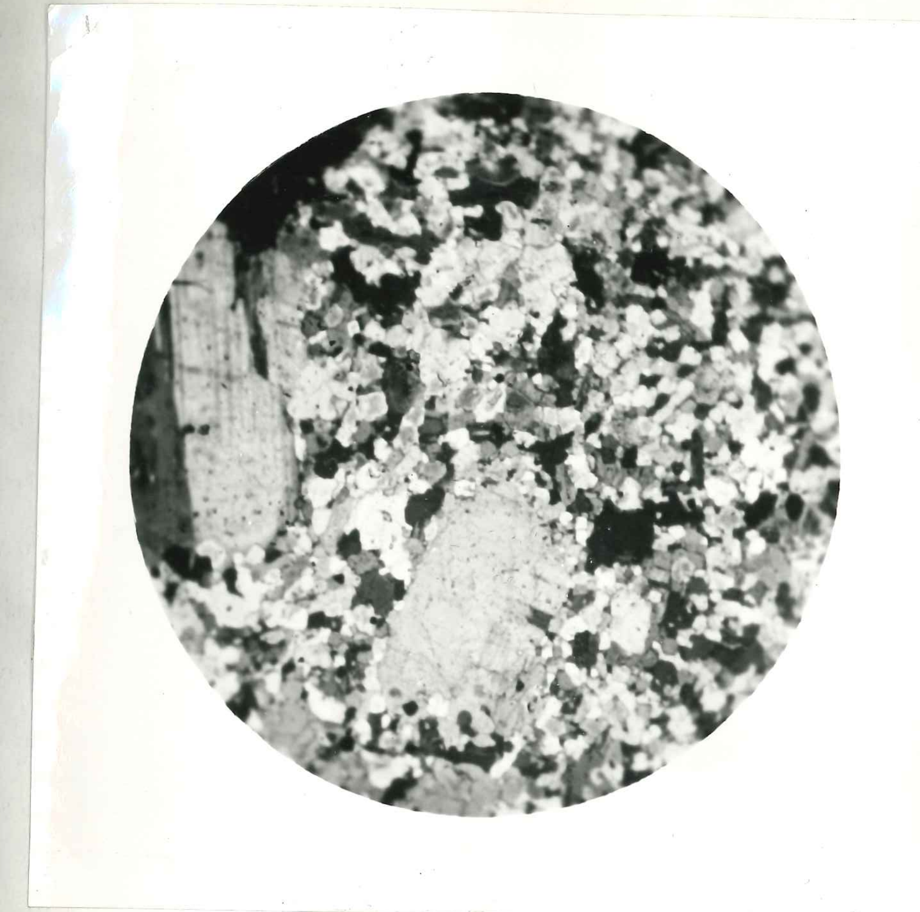
The fine grained granitic appearing rocks occurring at the south end of the Preacher granite near Lower Wildcat Lake have a variety of textures. These include: first, granite and granodiorite porphyries with large grains of quartz, oligoclase and orthoclase in a fine grained groundmass; second, microgranites consisting of quartz, oligoclase, orthoclase, hornblende and biotite in a fine grained equigranular texture; and third, fine grained granophyres which have large crystals of oligoclase surrounded by micropegmatitic intergrowths of quartz and orthoclase. A large outcrop of leucocratic granite porphyry southwest of Lower Wildcat Lake is similar in megascopic appearance to the rock near Nordrum Lookout described above. It has a fine grained groundmass of

PLATE 40

Photomicrograph of "granite porphyry" from the vicinity of Nordrum Lookout showing the development of porphyroblasts of oligoclase in a fine grained granoblastic groundmass. (x-Nicols; x 12) quartz, orthoclase, oligoclase and biotite in which porphyroblasts of oligoclase, quartz and orthoclase are seen in all stages of growth from small amoeba shaped grains, only slightly larger than the grains of the groundmass, to large fairly well formed grains showing some straight crystal faces (cf Plate 41).

Other granite porphyries are less conspicuously porphyroblastic since all the grains of the groundmass have had considerable crystalloblastic growth. Frequently this groundmass contains elongated feldspar grains in a crude parallel structure suggesting flow (cf Plate 42). In view of the crystalloblastic texture of the rock the origin of this alignment of feldspar grains is of interest. The same parallel alignment of feldspar grains is visible in a thin section of a specimen from an outcrop of quartz biotite granulite which occurs as an inclusion within the Preacher granite east of the Pratt River (cf Plate 43). This rock, which was originally a feldspathic graywacke of the Calligan formation similar to those outcropping on the west side of the Pratt River still has a clastic appearance in the outcrop but in thin section the rock shows evidence of considerable recrystallization. The small recrystallized feldspar grains are developing a lath-shaped subhedral outline. Since the rock still retains a clastic appearance both megascopically and to a less extent microscopically it suggests that the movement leading to the formation of alligned lath-shaped feldspars need not be large nor involve a liquid magma, but can be of the nature of plastic

PLATE 41



Photomicrograph of "granite porphyry" from near Lower Wildcat Lake showing development of twinned feldspar porphyroblasts in a fine grained granoblastic groundmass. (x-Nicols; x 12)

PLATE 42

Photomicrograph of "granite porphyry" from outcrop south of Lower Wildcat Lake, showing the development of lath shaped crystalloblastic feldspar in groundmass. (x-Nicols; x 15)

PLATE 43

Photomicrograph of granulite inclusion in Preacher granite east of the Pratt River, showing development of alligned feldspar laths. (x-Nicols; x 40) flow or adjustment to stress.

One specimen from near the contact between the fine grained granitic rocks of the Preacher granite mass and massive greenstones of the Lake Wildcat Metamorphics has some large porphyroblasts of quartz and oligoclase in a fine grained groundmass similar to that of the granulite near the Pratt River described above. Some of the quartz in the groundmass is in optical continuity with one of the large quartz porphyroblasts (cf Plate 44). In the same rock biotite is developing around the boundaries of quartz and feldspar grains and in cracks in the quartz.

As the amount of the larger porphyroblasts of quartz and feldspar increases and the amount of groundmass decreases the granite porphyries approach the coarse grained Preacher granite in appearance. With increased potash metasomatism the original oligoclase porphyroblasts become replaced by orthoclase and the rock becomes more granitic in composition.

Granophyric granite

In the granophyric granites large quartz grains and usually some oligoclase grains are contained in a dull white to light gray groundmass. Under the microscope the groundmass is seen to be composed of a micropegmatitic intergrowth of quartz and orthoclase.

The amount of micropegmatite in the granophyres varies. A specimen from the south side of Mt. Garfield consists of seventy per cent of a micropegmatitic intergrowth of quartz and

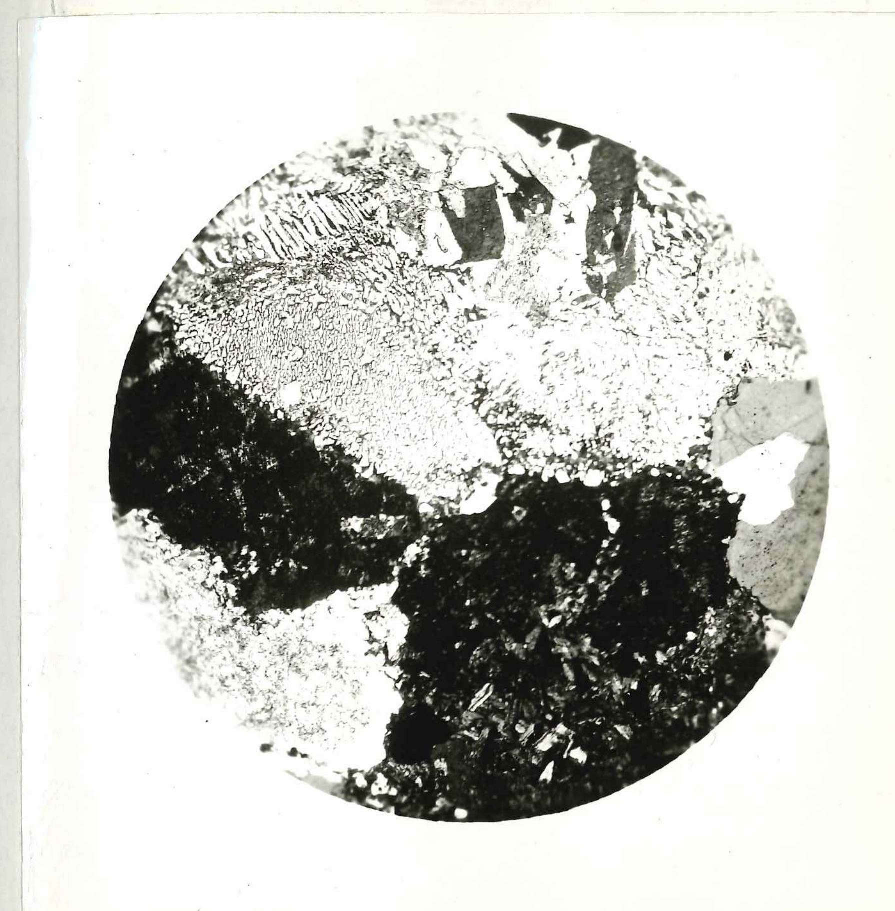
PLATE 44

Photomicrograph of "granite porphyry" from near the southern border of the Preacher granite south of Lower Wildcat Lake. Some of the quartz in the groundmass is in optical continuity with the large quartz grain. Some late biotite is growing along fractures in the quartz. (x-Nicols; x 15) orthoclase, ten per cent of rounded, somewhat embayed quartz grains, ten per cent of large irregular grains of microperthite, five per cent of irregular grains of oligoclase apparently being invaded and replaced by orthoclase and quartz, and five per cent of mafics. Other specimens have less micropegmatite.

While the quartz and orthoclase form a typical intergrowth in that the adjacent quartz patches have simultaneous extinction, only occasionally do the boundaries have the sharp angular appearance common to some graphic intergrowths. Rather, the quartz varies widely from elongated blebs, parallel within one small area but not within the whole specimen, to rounded irregular grains surrounded by orthoclase (cf Plates 45 and 46). The ratio of quartz to orthoclase within the micropegmatite is near 50-50. This is considerably different from the theoretical twenty-six per cent quartz and seventy-four per cent orthoclase which is the eutectic mixture of these two constituents. The character of these intergrowths suggests growth in the solid state and penetration by replacement.

The relation of the larger grains in the granophyres to the micropegmatitic groundmass varies. A fine grained microgranite outcropping a quarter mile northwest of Nordrum Lookout is light gray in color, fine grained, and is similar in megascopic appearance to some of the granulites of the Calligan formation. In thin section the rock is seen to consist of forty-five per cent quartz, twenty-five per cent ortho-

PLATE 45



Photomicrograph of granophyric Preacher granite from Garfield Mountain showing a variety of patterns of micropegmatite. (x-Nicols; x 15)

PLATE 46

Photomicrograph of granophyric Preacher granite showing irregular shaped aggregate of small biotite grains, some growing along crystal boundaries. (Plain light; x 15)

clase, twenty per cent oligoclase, and ten per cent irregular shaped grains of hornblende, biotite, and magnetite. Some of the quartz occurs as poikiloblastic grains inclosing small angular orthoclase and oligoclase grains, most of which do not have the same optical orientation. The simultaneous extinction of the quartz over a considerable area in the section gives the groundmass a somewhat micropegmatitic appearance. It is possible that this rock represents a more advanced stage of granitization of the granulites in which the growth of quartz and the replacement of oligoclase by orthoclase has destroyed the original clastic textures.

In some cases the boundaries between large oligoclase grains and surrounding micropegmatite will be straight lines following the crystallographic directions of the plagioclase. This would indicate replacement of earlier oligoclase by micropegmatitic material. In order to get this kind of arrangement during replacement there would need to be a solutional redistribution of material in the solid rock somewhat comparable to the manner in which small grains of hornblende and quartz coalesce into larger porphyroblasts. However, since most of the granophyric granites contain no relics of a clastic texture it is not possible to say to what extent they have formed by replacement of clastic derived granulite.

Inclusions of quartz diorite in Preacher granite

Within the northern part of the Preacher granite mass are exposed numerous inclusions of quartz diorite. These vary in size from large areas fifty to one hundred feet across to small blocks a few feet in size. The textures of the quartz diorites in these inclusions present all the variations seen in the quartz diorites around the margins of the Preacher granite. The inclusions are only conspicuous in the northern part of the Preacher mass.

One small inclusion which may be described as typical is exposed above the trail along the south side of the Snoqualmie Middle Fork opposite Mt. Garfield, about one-fourth mile below Tin Cup Joe Creek. It is an irregular shaped block of quartz dioritic material about three feet wide and six feet long. This block is surrounded by a zone of fine grained dark colored dense-appearing rock which passes outward into granite. Inside the dioritic block are some rounded patches of granite one-half to two inches across.

The quartz diorite in the block has a crystalloblastic texture which resembles the ten foot zone next to the granite outcrop along the Quartz Creek road and is also similar to parts of the quartz dioritic border to the Preacher granite on Garfield Mountain. It consists of andesine feldspar, hornblende, quartz, and biotite grains in a finely granular, somewhat clastic appearing groundmass. A few grains of oligoclase, quartz and bluish green hornblende larger than the rest seem to be growing by coalescence of some of the smaller grains. The granitic patches in the quartz diorite are composed of large quartz and oligoclase grains with some micropegmatite and represent centers of accelerated growth with some potash metasomatism. The large quartz grains in these patches have undulating extinction and some fractures, but the borders of the patches are gradational into the surrounding quartz diorite and thus differ from the blocks inclosed in quartz diorite in the vicinity of Quartz Creek previously described. The dense appearing borders of the inclusion are composed of fine grained mortar produced by mechanical granulation of the constituents of the quartz diorite; there is some dragging out of the granulated material. It grades outward into sheared granite.

In the granulated zone there is considerable magnetite, some of it associated with biotite in such a fashion that it suggests a derivation from the original mafics in the quartz diorite. Toward the outside of this granulated zone the fine material begins to recrystallize into a mosaic of quartz and feldspar with scattered magnetite grains. Some large porphyroblasts of quartz and feldspar are contained in the granulated zone.

It appears on the basis of the observations noted above that this inclusion of quartz diorite in the Preacher granite is a relic of basic rock which has not been granitized although the original basic rock has been recrystallized and there has been some metasmatism.

Origin and Mode of Emplacement of the Preacher Granite

Various features have been described above which should be considered if an interpretation of the origin and the mode of emplacement of the Preacher granite is attempted. These critical features may be summarized as follows: (1) The granite mass shows numerous variations in texture. (2) There is abundant evidence of the replacement of earlier plagioclase by later quartz and orthoclase. (3) The mafics occur in ragged plates or in irregular shaped aggregates of small grains and have a tendency to grow along crystal boundaries. (4) Some of the granite porphyries and microgranites near the borders of the mass have relict clastic textures resembling those in the altered feldspathic graywackes, and the contact between these microgranites and the feldspathic graywackes in the northwestern part of the granite mass is gradational. (5) In some of the granite porphyries the large feldspar and quartz porphyroblasts become numerous and the amount of groundmass is small; thus it appears that transitions exist from feldspathic graywacke to coarse grained Preacher granite. (6) In its northern parts the Preacher granite contains quartz diorite inclusions which are interpreted as basic rocks, probably part of the Mt. Garfield andesites, which have been recrystallized and locally been incompletely granitized but in general have resisted granitization more than the feldspathic graywackes. (7) The northern border of the Preacher granite shows evidence of much brecciation and faulting and on Mt. Garfield the granite together with some partially granitized quartz biotite has been faulted up against only slightly metamorphosed andesites. (8) The faulting mentioned above apparently occurred at a time when temperatures were still fairly high and the recrystallizing and granitizing solutions were still active because the brecciated zones have been recrystallized, and in some cases granitization is more advanced in the brecciated zones than elsewhere. (9) Some mobility in the Preacher granite is suggested by the presence of a parallel structure in elongated feldspar laths in some of the microgranites but the development of similar parallel structure in granulites which still retain some clastic appearance indicates this mobility was apparently in the form of plastic flowage under stress rather than movement of a liquid magma. (10) Some of the granophyres in which euhedral plagioclase grains are symmetrically surrounded by micropegmatite are of uncertain origin but in many of these rocks replacement features are evident. (11) The same processes which lead to the formation of the Preacher granite took place in the Quartz Creek Complex but the granitization there is more local in extent and not as far advanced.

On the basis of the criteria listed above much of the Preacher granite can be considered as having originated by granitization of feldspathic graywackes of the Calligan formation, with the associated quartz diorites having formed by recrystallization of portions of the Mt. Garfield volcanics. In some cases these may have been dikes in the Calligan graywackes. The Preacher granite and its associated quartz diorites has then moved upward by a combination of faulting which is evident at its northern border, and of some plastic flowage, which is visible at least at some places.

The emplacement of the Preacher granite and its relation to the Quartz Creek Complex will be discussed further in connection with the regional structure.

Sunday Granite

General Features

A rather small area of granite occurs on the ridge between Philippa Creek and Sunday Creek from the edge of the alluvium along the Snoqualmie River North Fork and Sunday Creek to an elevation of 3200 feet. The outcrop is less than a square mile in area south of the river but microgranites outcrop north of the river and these have been shown on the map as part of the Sunday granite.

On the south at 3200 feet elevation the granite contacts tuffs and tuffaceous graywackes as noted by a change in the type of float. One block of water laid tuff a few hundred yards from the contact contains abundant angular andesite fragments (cf Plate 21) which are not highly altered. A clue to this might lie in the occurrence of some trenches along the crestline between this tuff and the contact, which are oriented N50°E and which may mark the location of faulting which accompanied the emplacement of the granite. As in the case of the Preacher granite, the temperature of this granite during emplacement might have been fairly low. On the basis of very limited exposures showing any visible strike and dip the tuffaceous rocks south of this granite and those to the north seem to dip away from the granite suggesting that there may have been some pushing up of the overlying rocks.

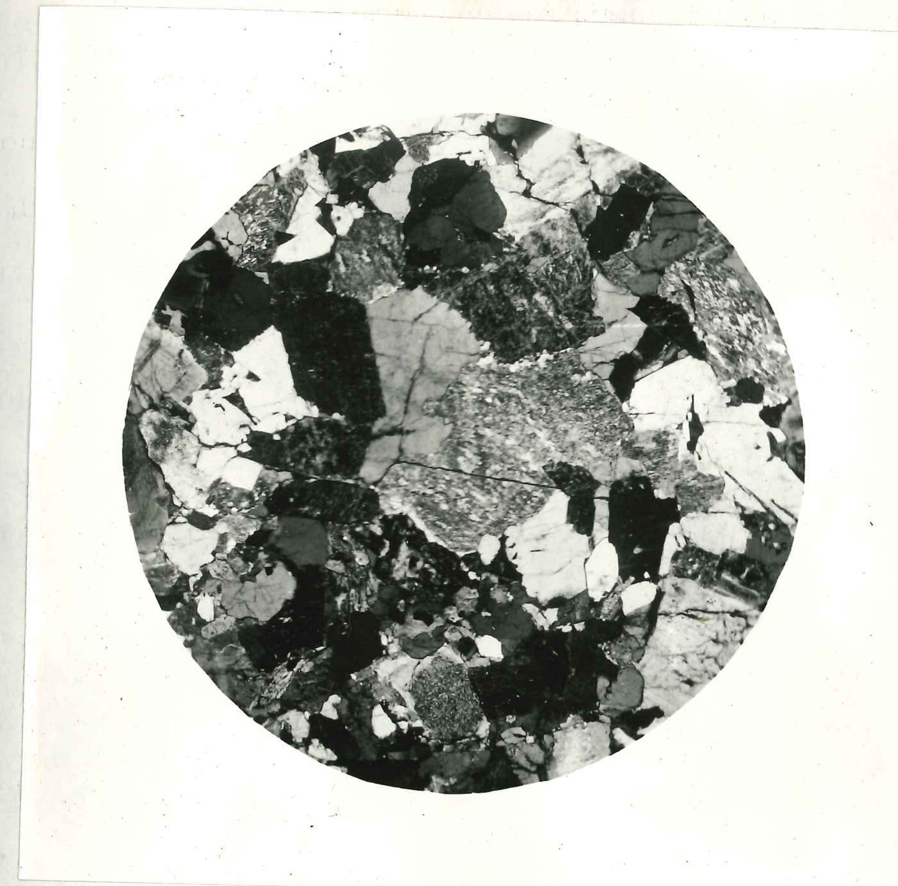
Several small granitic bodies ten to several hundred feet wide were observed on three sides of the Sunday granite. Because of the fact that exposures in the heavy timber in this vicinity are limited to a few road cuts and pieces of float, the true extent or shape of these bodies was not determined, but they seem to be concentrated around the Sunday granite. In these small bodies the most widely distributed rock type is a leucocratic granite porphyry. This rock is exposed as a thirty foot dike cutting shales and graywackes on the Weyerhauser logging road up Big Creek. Bodies of similar rocks are exposed along the lower Weyerhauser logging road along the north side of the North Fork of the Snoqualmie River opposite the mouth of Sunday Creek. Here they occur with other rocks of micrograniti c and microgranodioritic character, and appear to cut argillites and tuffaceous sediments of the Calligan formation. There are no clear-cut intrusive contacts here and some of the contacts appear to be fault contacts.

Petrography of the Sunday Granite

The Sunday granite is a medium grained leucocratic rock composed of quartz, feldspar and biotite grains in a white, rather sugary base. Under the microscope the granite is seen to consist of a few larger quartz, orthoclase and oligoclase grains in a slightly finer equigranular fabric of quartz and orthoclase, part of which forms coarse intergrowths. The orthoclase occurs mainly as microperthite. The texture is crystalloblastic and there are some areas of finer grained granoblastic mosaic of quartz and feldspar (cf Plate 47).

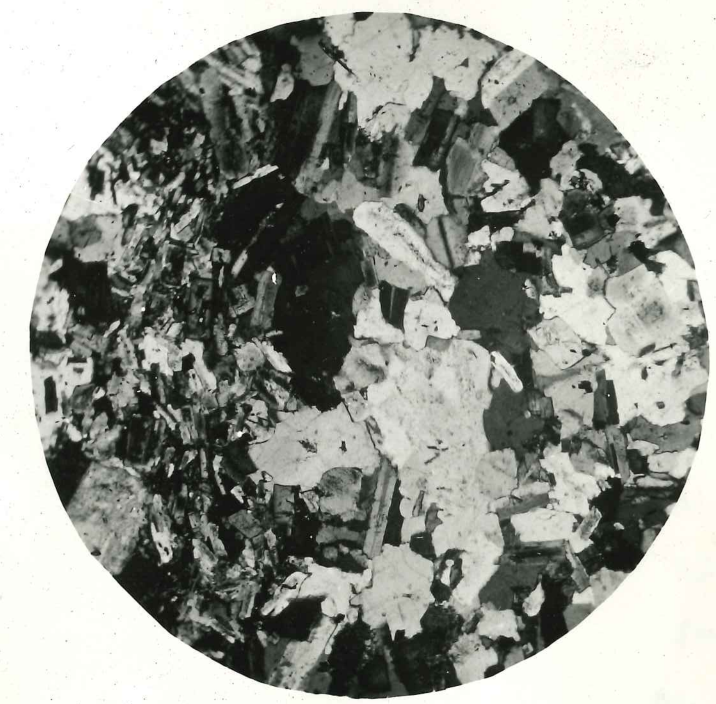
Farther south up the ridge between 2500 and 3200 feet elevation the granite contains some areas of microgranite. This microgranite has essentially the same minerals as the granite, i.e. quartz, orthoclase, oligoclase and biotite, but the rock is slightly richer in oligoclase and biotite and some of the quartz and orthoclase intergrowths have a spherulitic form. A thin section of the microgranite shows some thin bands in which the feldspar and quartz and biotite are fine grained and show some parallel structure suggesting flow (cf Plate 48). These finer grained areas are similar in texture to the granulite forming an inclusion in the Preacher granite (cf Plate 43). However the bulk of the slide shows a coarser grain size and a granoblastic texture with large quartz grains replacing plagioclase and poikiloblastically inclosing earlier grains of feldspar. Some late radial intergrowths are replacing

PLATE 47



Photomicrograph of specimen of Sunday granite from outcrop between Philippa Creek and Sunday Creek showing microperthite (cloudy) and quartz and plagioclase (clear), and a plate of biotite altering to chlorite. (x-Nicols; x 12)

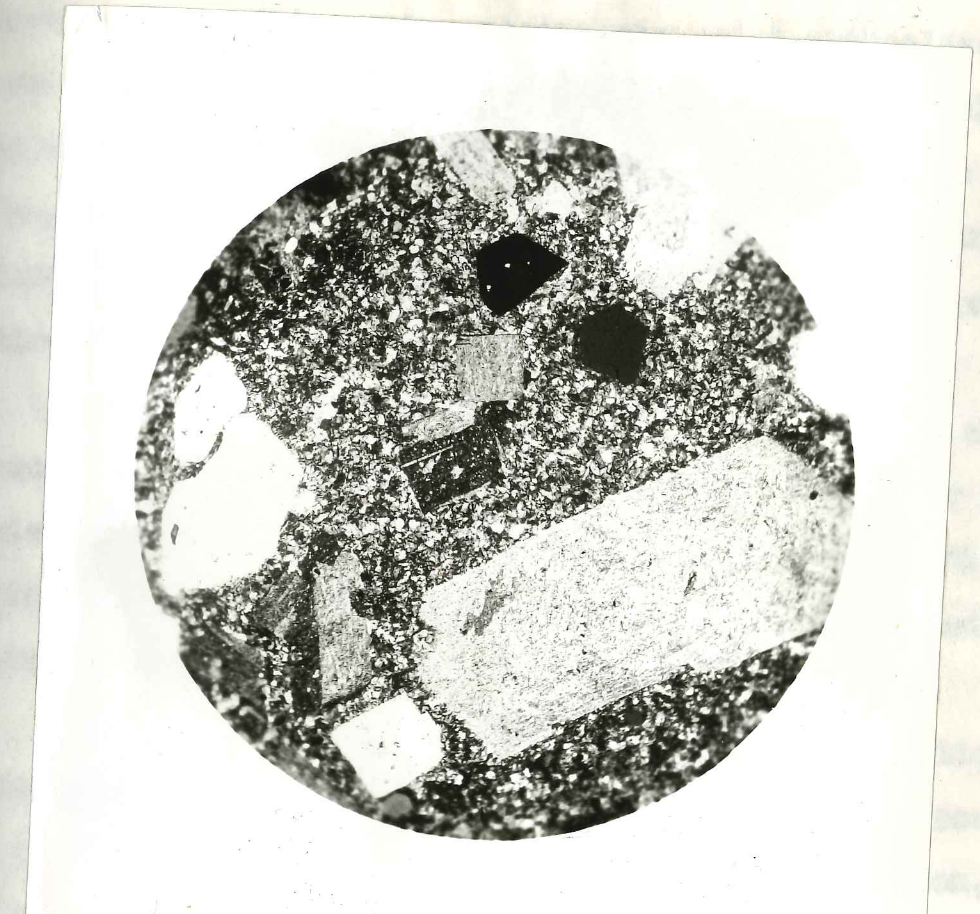
PLATE 48



Photomicrograph of a finer grained border phase of the Sunday granite. The narrow band on the left shows local parallel structure suggesting flow, while the bulk of the rock has a granulitic texture as seen on the right. (x-Nicols; x 12) the granulitic mosaic. These intergrowths are mostly quartz and feldspar but there is also some pale hornblende approaching a "feathery hornblende" type. The presence of a metamorphic granulitic texture side by side with evidence of flow suggests that this rock may represent mobilized granitized material.

The granite porphyry on the Big Creek road is a leucocratic rock varying from nearly white to light gray in color in the central portion, with often a slight green tint due to the presence of scattered shreds of secondary chlorite as the only mafic mineral present. In the main body of the dike the rock is usually not noticeably porphyritic in the hand specimen because of the overall light color. Near the borders however the groundmass is usually a slightly darker green in color due to more abundant chlorite and then the white feldspar phenocrysts stand out more distinctly and the rock appears plainly porphyritic. The phenocrysts are quartz, orthoclase and oligoclase. The quartz occurs as corroded grains with inlets of the groundmass. The orthoclase forms subhedral crystals and is partly altered to sericite. The plagioclase is also altered to sericite and calcite. The latter mineral also occurs in some irregular shaped patches in the groundmass. While the phenocrysts are from one to three millimeters in diameter the grains of the groundmass are of the order of 0.1 millimeter in size (cf Plate 49). Mafic minerals are limited to a few ragged patches of secondary chlorite.

PLATE 49



Photomicrograph of a specimen of granite porphyry from a dike cutting graywackes and tuffs along the logging road up Big Creek. Large crystals of orthoclase, plagioclase and quartz are contained in a fine grained groundmass.

(x-Nicols; x 12)

Alongside one of the outcrops of granite porphyry on the Weyerhauser logging road on the north side of the river opposite Sunday Creek is an outcrop of very fine grained microgranite. This rock contains elongated orthoclase laths about 0.2 millimeters wide and one millimeter long, elongated hornblende and biotite grains, both partly altered to chlorite, together with intergranular quartz. It is of interest primarily because of an imperfect parallel structure of the orthoclase and mafics suggesting flow structure.

Another outcrop a short distance west of the above microgranite shows more granite porphyry with a finer grained variety between it and some fine grained tuff. The finer grained variety has the appearance of a porphyritic coarse grained rhyolite.

Thus it is apparent from microscopic examination that while these minor granitic bodies vary greatly in appearance due to differences in texture and amount of alteration, they are all of similar mineral composition. The structure in this area is not well enough exposed to determine the relation between the granite porphyries, some of which have an igneous appearance, and the coarser grained granite and microgranites which have a crystalloblastic texture. The possibility exists that the porphyries may be dikes composed of mobilized material derived from a partially mobilized central granite body.

Snoqualmie Granodiorite

General Features

The "Snoqualmie granodiorite," as defined above, covers about forty-two square miles within the map area. The main mass of the granodiorite is in the northeastern part of the region and extends over a large area beyond the map boundaries.

A long tongue, one to two miles wide, of this granodiorite extends from the main mass in the northeast in a westerly direction through Goat Mountain and along the divide between Lake Calligan and Lake Blethen basins, and then swings southward through Bessemer Mountain to the vicinity of the Middle Fork of the Snoqualmie River, where, on the CCC road, it is less than a mile in width.

Another area of similar granodiorite outcrops on the slope southwest of the Pratt River. Still another belt about one mile in width of this granodiorite cuts across the Preacher granite in the southeastern part of the map area, forming the bulk of 5885 feet high Mt. Roosevelt.

These separate areas of granodiorite are all considered as one unit because they are all of similar composition and texture, and they are correlated with the Snoqualmie granodiorite southeast of the map area. Specimens picked at random from such widely separated outcrops as along Granite Creek, along the Taylor River, from the vicinity of Cougar Creek, and from the head of Bear Basin all consist of the same type of directionless granodiorite.

Petrology

The granodiorite is a light gray medium to coarse grained rock. It is non-porphyritic. The important mineral constituents are, in the order of decreasing abundance, plagioclase, orthoclase, quartz, hornblende, and biotite.

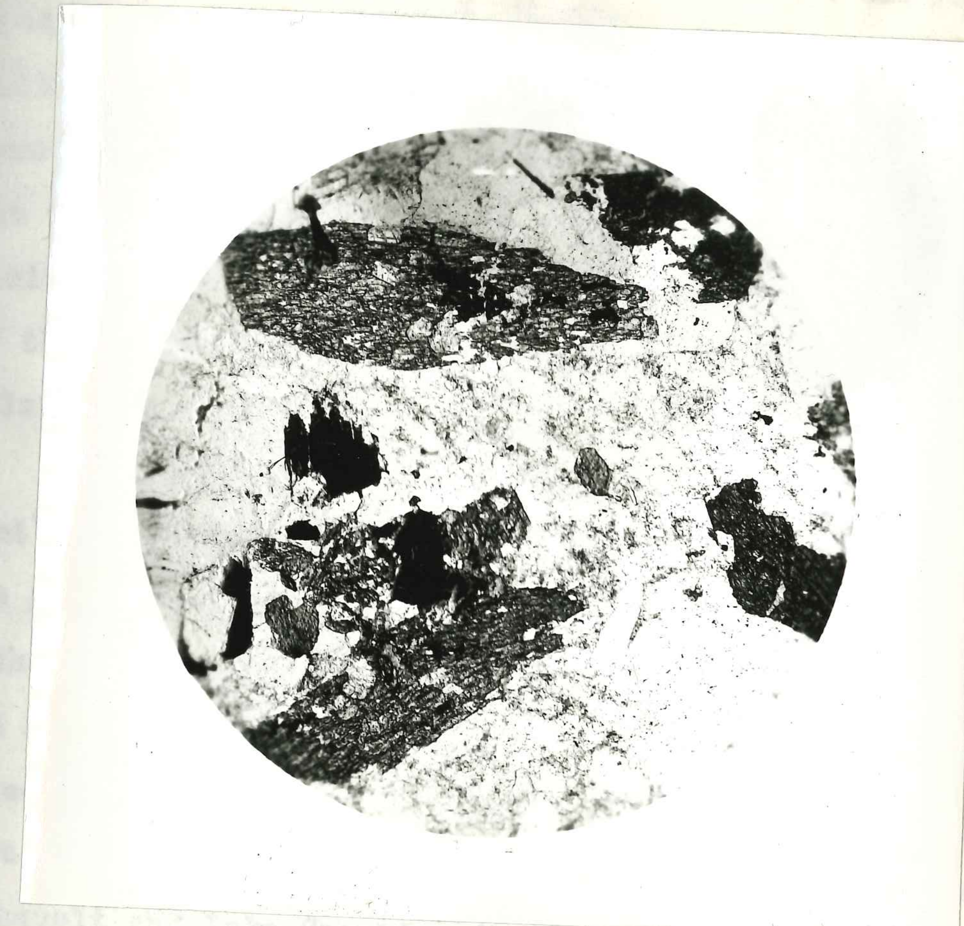
A specimen taken from along Cougar Creek at an elevation of 3540 feet, in the northeastern part of the map area, is typical of the granodiorite. It consists of forty per cent plagioclase feldspar, twenty per cent potash feldspar, twenty per cent quartz, and twenty per cent hornblende plus biotite.

In all the granodiorites part of the biotite is chloritized and some magnetite is usually present. The texture is coarse grained. The plagioclase is andesine, which varies slightly but is usually near $An_{40}Ab_{60}$. It is subhedral and part of the crystals are zoned. The potash feldspar is predominantly orthoclase. A few grains of microcline were seen in the specimen from Cougar Creek. Some microperthite is usually present. The orthoclase grains are anhedral and very often enclose grains of the other minerals (cf Plate 50). The quartz is usually intergranular and appears to have formed fairly late. Hornblende commonly, but not always is subhedral (cf Plate 51), and sometimes is twinned. It often forms poikiloblastic grains or loose aggregates suggesting that it formed

PLATE 50

Photomicrograph of a specimen of Snoqualmie granodiorite from an outcrop along the CCC road showing large anhedral grain of orthoclase enclosing subhedral grains of plagioclase and also smaller grains of quartz and biotite. (x-Nicols; x 15)

PLATE 51



Photomicrograph of specimen of Snoqualmie granodiorite from Devil's Canyon showing large subhedral grains of hornblende and ragged biotite grains growing along crystal boundaries. (Plain light; x 15)

by collective crystallization. The biotite is usually in more irregular shaped plates and often partly altered to chlorite. As a rule the amount of hornblende slightly exceeds the amount of biotite. The texture is somewhat crystalloblastic, which seems to be due mainly to replacement of some earlier plagioclase by later quartz and orthoclase and due to the growth of some late biotite along crystal boundaries. This potash metasomatism is restricted to the confines of the granodioritic mass and must therefore be genetically related to this rock mass.

Some dark colored, more basic inclusions less than a foot in diameter occur, but are not very abundant. Within the granodiorite are some areas of more leucocratic granitic rock. Some lighter portions are well exposed in Bear Basin and are described in connection with the Bear Basin mine. These more leucocratic areas also have been observed on the east side of Goat Mountain, and on the slope between Mt. Roosevelt and Lake Caroline in the southeastern part of the map area. In both the Mt. Roosevelt and Goat Mountain areas some small veinlets and pockets of tourmaline occur and between Mt. Roosevelt and Lake Careline pockets containing long prisms of epidote are also numerous.

Contacts and Border Zones of the Snoqualmie Granodiorite

The contacts of the granodiorite with the graywackes and argillites of the Calligan formation are usually quite sharp. The contacts of the granodiorite with the tuffs and andesites are less sharply marked and more irregular, due to the fact that the metamorphosed volcanic rocks are so near the composition of the granodiorite. There is usually no marked decrease in grain size or noticeable change in composition along the margin of the granodiorite. The quartz diorite outcropping near the edge of the granodiorite in the vicinity of the Lennox mine is the one exception which was observed.

Vicinity of Mt. Phelps

The western boundary of the granodiorite in the vicinity of Mt. Phelps is quite irregular and some of the meta-andesites have a dioritic appearance similar to the appearance of the Snoqualmie granodiorite at this point. South of Mt. Phelps the contact is buried beneath the alluvium at the junction of the Lennox and Snoqualmie Rivers.

Vicinity of the Lennox River

Along the Lennox River mine to market road above the Lennox mine camp there occur granitic-appearing rocks of variable texture. These are mostly fine-grained quartz diorites. However, associated with these quartz diorites are some migmatites which do not have a uniform texture but contain some dark colored streaks and patches which can be identified microscopically as recrystallized tuffaceous material, and the more leucocratic portions of these rocks are composed mainly of quartz in irregular veinlets and patches, with some plates of biotite one-half inch across. There is no sharp boundary between the recrystallized tuffaceous material and the quartz diorite proper. The quartz diorite extends across to the south side of the Lennox River and is well exposed in the long cross-cut being driven by the Priestley Mining and Milling Company. In several exposures along the road and also in the cross-cut the fine grained quartz diorite is criss-crossed by numerous veinlets and patches of coarser grained, more leucocratic rock. These coarser grained patches at times make up more of the rock than the fine grained quartz diorite, the latter appearing as inclusions (cf Plate 52).

The quartz diorite proper is a medium gray, fine grained, fresh appearing rock composed of subhedral elongated grains of andesine feldspar, subhedral green hornblende, nearly colorless orthorhombic pyroxene, and some inter-granular quartz. The pyroxene usually is found in the centers of hornblende grains, but one specimen from the cross-cut contains numerous euhedral grains of orthorhombic pyroxene. This is faintly pleochroic, Z = very pale green, X and Y = very pale yellow. It is probably between bronzite and hypersthene in iron content.

Locally in the tunnel the quartz diorite shows good parallel structure of the feldspar laths (cf Plate 53). The veinlets and patches of leucocratic rock within the quartz

PLATE 52

Photograph of a migmatitic border of the Snoqualmie granodiorite as exposed along the Lennox River mine to market road. The darker areas are fine grained quartz diorite. The more leucocratic rock is coarser grained and rich in quartz.

PLATE 53

Photomicrograph of quartz diorite from adit being driven by Priestley Mining and Milling Company. The feldspars have good parallel structure suggesting flow. The light gray mineral with high relief is hypersthene. (x-Nicols; x 15)

diorite, mentioned above, contain abundant quartz, some of which incloses numerous feldspar and hornblende grains. Biotite, which is almost absent in the fine grained quartz diorite, forms some large plates in these lighter colored portions. A few grains of potash feldspar are present. This leucocratic portion of the migmatites is similar in appearance to the main mass of the Snoqualmie granodiorite although it does not show as much potash feldspar as is found farther inside the main body of granodiorite.

To the east of this area of quartz diorites is an irregular area of hornfels and granulites surrounded by granodiorite, which can be seen on the map to be roughly a mile in diameter. The contact between these rocks, which are metamorphosed graywackes and tuffaceous sediments of the Calligan formation, and the granodiorite can be observed in the short tunnel now being driven on the Langer claims about a mile up the Lennox River mine to market road from the Lennox property. The rather abrupt contact here contrasts with the gradational contact with the volcanic rocks as described above.

Another locality where the contact between the granodiorite and the Calligan formation is quite conspicuous is in the vicinity of Bare Mountain Lookout between Bear Creek and Paradise Lake. The peak known as Red Butte consists of dark reddish hornfelses, which contrast sharply with the light colored granodiorite east of the peak. Some of these Red Butte hornfelses contain tourmaline, and just west of the peak between the Bare Mountain Lookout and Paradise Lake the highly metamorphosed rocks include some narrow bands of amphibolite along with garnet biotite granulites, all indicating thermal metamorphism.

Vicinity of Sunday Lake

The western margin of the granodiorite, after crossing the ridge between Sunday Creek and the Lennox River east of the Lennox mine continues to the southwest near the south end of Sunday Lake and then is exposed in fairly open cliffs south of the lake below Twin Peaks. In a canyon just south of the lake the granodiorite can be observed in contact with the Calligan formation, which is metamorphosed with the production of some garnet. A few small dikes of aplitic character penetrate the sediments a short distance from the contact. These dikes become richer in quartz with increasing distance from the granodiorite and finally pinch out.

Vicinity of Lake Calligan

The contact continues in a nearly straight line past Lake Philippa and can be observed again on the ridge between Lake Philippa and Lake Calligan, still contacting argillites and graywackes. The strike of these rocks is nearly parallel with the contact, but the dips are variable, there being some overturning of folds (cf Plate 54). The granodiorite has narrowed here to about two miles and appears to be in part concordant with the sedimentary rocks.

PLATE 54

Photograph of overturned fold in argillites and graywackes of the Calligan formation east of Lake Calligan near the contact with the Snoqualmie granodiorite.

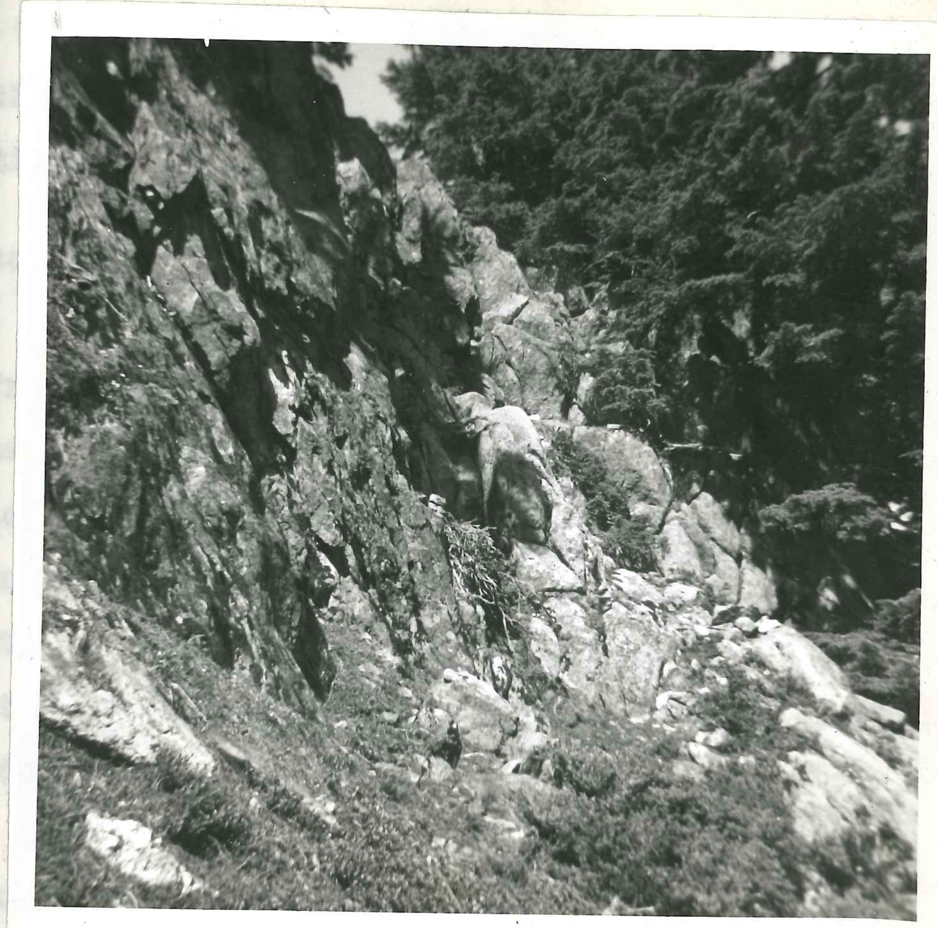
Vicinity of the CCC road

The granodiorite is about one mile wide where it crosses the ridge separating the drainage areas of the North and Middle Forks of the Snoqualmie River in the vicinity of Mt. Bessemer. Still farther south some good exposures of the contact of granodiorite with the sedimentary rocks are visible in the deep rock cuts along the CCC road north of the Snoqualmie Middle Fork. Here the main body of granodiorite has narrowed to less than a mile, but parallel to the western boundary of this main body of granodiorite and separated from it by metamorphosed argillites and graywackes is a five hundred foot wide parallel body of granodiorite. Even this small mass of granodiorite shows no chilled borders, the granodiorite remaining coarse grained to the very margin of the mass. The granodiorite appears to cut at a small angle across the structure of the sedimentary rocks and two to six inch wide veinlets and some small patches of granitic material occur in the sediments a few feet from the contact. The granodiorite ends at the alluvium along the Middle Fork of the Snoqualmie River.

Southwest of the Pratt River

The contact of the granodiorite body southwest of the Pratt River with argillites of the Calligan formation can be well observed on the ridge southwest of the Pratt River (cf Plate 55). It is fairly straight and there appears to have been some faulting connected with the emplacement. But the

PLATE 55



Photograph of contact between the Snoqualmie granodiorite and the Calligan formation on the ridge southwest of the Pratt River. The light colored granodiorite is on the right and the dark purplish gray metamorphosed sedimentary rocks are on the left.

thermal metamorphism of the Calligan formation with the resulting dark purple coloration, and the presence of small veinlets of granitic composition penetrating short distances into the metamorphosed argillites shows that all the crystall growth in the granodiorite had not taken place prior to the faulting.

Contacts with other granitic rocks

The contact between the Snoqualmie granodiorite and the Preacher granite in the southeastern part of the map is exposed along the ridge west of Mt. Roosevelt. Most of the contact proper is buried under a small depression which seems to run parallel to it, but at one place above Lake Caroline an outcrop shows an irregular contact of granite and granodiorite (cf Plate 56). The thin projections of Snoqualmie granodiorite into the Preacher granite suggest that this is a sharp replacement contact with the granite replacing granodiorite, which would make it appear that the granite is the younger of the two.

The contact between the Snoqualmie granodiorite and the rocks of the Quartz Creek Complex is not so well defined as are the contacts with the Preacher granite or the sedimentary rocks because the rock contrasts are not so great. However, the gray tonalites in the northern part of the Quartz Creek Complex are darker colored and usually finer grained than the granodiorite. The point of change of rock type is

PLATE 56

Photograph of contact of Snoqualmie granodiorite (dark) with Preacher granite (light) south of Lake Caroline.

easily recognized on the ridge between the Quartz Creek and Sunday Creek drainage areas directly south of Sunday Lake, but the actual contact is covered. This contact can be observed to continue in an easterly direction to a point just down-stream from Mowich Lake. The exact location of the remainder of this contact as shown on the map is open to some question. The line shown on the map serves to separate the area of homogeneous Snoqualmie granodiorite occurring north of Cougar Lake and east of Marten Lake from the more heterogeneous granitic rocks of the Quartz Creek Complex. No sharp contact was observed in this vicinity but the manner in which the granodiorite east of Marten Lake cuts across the structure of the Quartz Creek Complex and the presence of considerable brecciation in the rocks outcropping west of Marten Lake suggests that there has been some movement here and the area of granodiorite to the east has moved up with respect to the rocks to the west.

Mode of Emplacement of the Snoqualmie Granodiorite

In considering a possible mode of emplacement of this granodiorite the following field and petrographic criteria seem significant: (1) The large bodies of granodiorite within the map area are similar in megascopic appearance and in their general composition and texture. (2) The contact relations between the granodiorite and the argillites and feldspathic graywackes of the Calligan formation indicate the granodiorite has moved to its present position accompanied by much deformation of the sedimentary rocks and by relatively low grade thermal metamorphism. In some cases the contacts appear to be faults but in every case small veinlets of quartz and feldspar penetrating the surrounding rocks are later than the faulting. (3) There are no chilled borders and no tendency for a porphyritic texture along the border of the granodiorite. (4) Evidence of any magmatic stoping is entirely lacking and the argillites and graywackes of the Calligan formation have in general been pushed way out of the way and highly deformed rather than penetrated by apophyses of the granodiorite. (5) In some cases, as near the mouth of the Lennox River, the granodiorite has a migmatitic border. (6) There is abundant evidence in the rock of the replacement of earlier plagioclase by later orthoclase and quartz giving the rock a somewhat crystalloblastic texture. This is confirmed by crystalloblastic growth of biotite in the quartz-feldspar intergranular.

Not enough detailed petrographic study was made of the granodiorite to arrive at any final decision concerning its genesis. Such a study should include the remainder of this large mass of granodiorite outcropping east of the map area. On the basis of the criteria listed above, it is believed the granodiorite within the map area moved to its present position in a plastic rather than a liquid condition. The final textures in the granodiorite appear to have resulted from the replacement of earlier plagioclase by later quartz and orthoclase and by some collective recrystallization of the mafics. Replacement has also occurred at some, but not all, of the contacts of the granodiorite with the meta-sediments and meta-volcanics. Some additional features concerning its emplacement will be discussed in connection with the regional structure.

REGIONAL STRUCTURES

Visible Folded Structures

Within the Calligan formation there are many variations in the trend of the folds. The fact that the folding becomes much more intense near the granitic masses, and that the trend of the folds tends to parallel the contacts, indicates that the structural pattern has been considerably modified by the emplacement of the granitic rocks.

In the northwestern part of the area, farthest from the large granitic bodies, small open folds are visible in some logging road cuts, accompanied by much minor faulting succeeded by the formation of numerous dikes. The Calligan formation here consists of interbedded graywackes, shales and tuffaceous rocks. During the folding the massive tuffaceous and graywacke beds acted as competent members while the interbedded shales acted as incompetent members. Most of the differential movement along bedding planes was concentrated in the shaly beds, and was accompanied by minor folding and contortion or intense brecciation. The thin bedded shale often acted as a plastic mass and moved from areas of high pressure to areas of low pressure where it now forms highly contorted lenses (cf Plate 11). The more brittle graywacke and tuffaceous beds have suffered a considerable amount of fracturing and faulting. These fractures are often of small displacement and locally flexures can be seen to pass into faults. This relatively open folding and accompanying faulting appears to be regional in extent as no completely flat lying beds were observed even at considerable distances from any exposed granitic bodies. This regional folding was earlier than the granodiorite and probably Laramide or early Tertiary.

Nearer the granitic bodies folding is more intense. Along the CCC road near the Snoqualmie River Middle Fork the graywackes and argillites have not only been quite strongly metamorphosed but also appear to have been isoclinally folded as is suggested by their nearly uniform steep dips. Compressive forces appear to have been acting during the emplacement of the granodiorite. On the ridge east of Lake Calligan the argillites and feldspathic graywackes close to the granodiorite are tightly folded and one overturned fold is visible in the cliffs (cf Plate 54).

The Map Pattern

While a lack of good bedding in the massive feldspathic graywackes of the Calligan formation, and the absence of visible stratification in the massive andesite breccias of the Mt. Garfield Volcanics makes it difficult to reconstruct the pregranitic structure in the central part of the area, some approximation of this structure is suggested by the map pattern.

On the basis of the petrographic evidence given in this thesis it appears that the Quartz Creek Complex is in general a migmatitic area with the following affiliations: First, the Area of Heterogeneous Granitic Rocks represents an area in which some rocks of the Calligan formation have been recrystallized and irregularly granitized to form rocks of quartz dioritic to granitic composition. Where there has been appreciable potash metasomatism in the rocks the result was to produce a rock similar to the Preacher granite. Second, the tonalite in the vicinity of Mowich Lake is a rock of uncertain origin which has been considerably metamorphosed. It does not extend outside the area of the Quartz Creek Complex and its relation to both the granodiorite and the Calligan formation is in doubt. Third, the Area of Fine Grained Quartz Diorites appears to represent basic rocks, probably belonging to the Mt. Garfield Volcanics, which have been recrystallized during the formation of the Preacher granite.

The Preacher granite appears to have originated mainly by the granitization of feldspathic graywackes of the Calligan formation. The presence of bodies of quartz diorite included in the granite might be explained in several ways. They might represent portions of the Mt. Garfield Volcanics which were interbedded with or folded into the Calligan graywackes, or they may be dikes of andesite or andesite porphyry similar to those seen cutting the Calligan formation to the west, and during the formation of the Preacher granite they have resisted the granitization which has completely transformed the surrounding graywackes. Some bodies of quartz diorite may also owe their position to the abundant faulting which is present in the northern part of the Preacher granite, since they often have cataclastic textures at their borders.

Towards the end of the formation of the Preacher granite, but while granitization and recrystallization processes were still active, the bulk of the Preacher granite southeast of the Middle Fork of the Snoqualmie River appears to have been faulted up so that on Mt. Garfield the Preacher granite, with a narrow intervening area of quartz diorite, contacts relatively slightly altered volcanics. An extension of this fault to the southwest along the south side of the Middle Fork of the Snoqualmie River appears very likely as the map shows an offset in the southwestern boundary of the Preacher granite near the mouth of the Pratt River. In this connection there is another feature which may be considered. The contact of the granodiorite west of the Pratt River with the Calligan formation, although as a whole curved on the map, is locally quite straight (cf Plate 54), and were it not for the veinlets of quartz and feldspar penetrating the Calligan formation near the contact, it would appear to be a fault. If the potash metasomatism in the granodiorite took place at the same time as the formation of the Preacher granite then these veinlets of quartz and feldspar could be related to this metasomatism. On this assumption the upward movement of the granodiorite southwest of the Pratt River can be considered as a faulting up related to the upward movement of the Preacher granite as noted on Mt. Garfield. This line of movement extending from Mt. Garfield in a southwesterly direction has been shown on the map as the Garfield fault.

If an attempt is made to reconstruct the pre-granitic structure by including the Area of Heterogeneous Granitic Rocks and the area now occupied by the Preacher granite as extensions of the Calligan formation, it would appear that the Calligan formation once surrounded the Mt. Garfield Volcanics in such a way as to suggest that the volcanics occupy a synclinal trough plunging to the east. This synclinal pattern is partially destroyed by the upward movement of the southeastern part of the volcanics along the Garfield fault. The fact that the contact between the base of the Mt. Garfield Volcanics and the rocks of the Quartz Creek Complex is at 1800 feet elevation in the small area of volcanics preserved on the ridge north of the Taylor River, but is below the lowest exposures at 1200 feet elevation on the southeast side of the Taylor River suggests that the base of the volcanics dips to the southeast in that locality.

The long tongue of granodiorite extending from Goat Mountain toward Bessemer Mountain would then appear to occupy an anticlinal area. The Mt. Phelps volcanic rocks and the interbedded graywackes in the vicinity of the North Fork of the Snoqualmie River in general show dips toward the northwest and thus would fall on the northwestern limb of this anticline with an increase in the volcanic admixtures in a northerly direction and upward in the section. The interpretations noted above are illustrated in a cross section in a northwest-southeasterly direction through the Quartz Creek Complex and the Preacher granite (cf Plate 57).

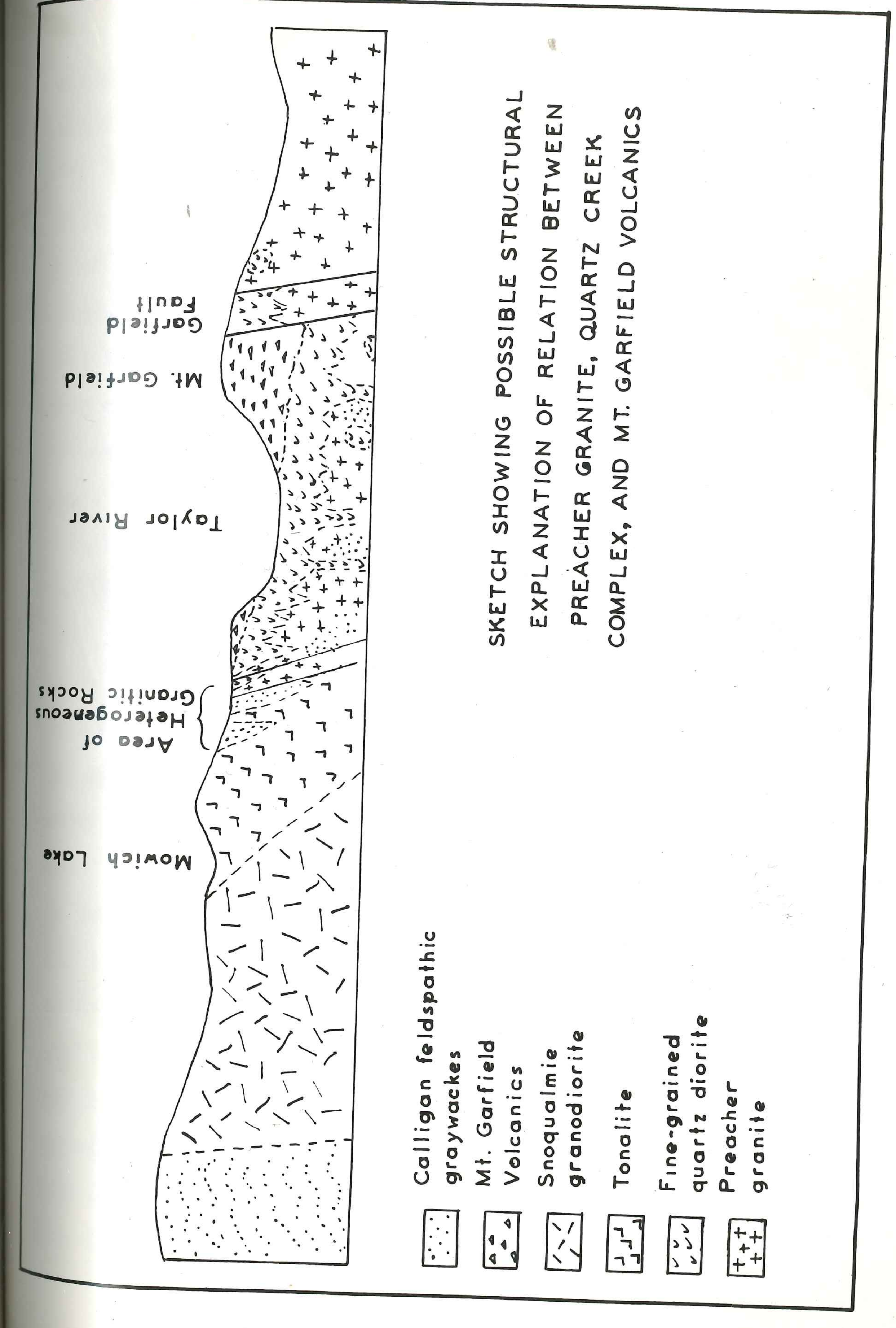
Since the fine grained granitic appearing rocks in the southeastern corner of the map area, near the rocks mapped by Smith and Calkins (9) as the Guye formation, appear to be partially granitized feldspathic graywackes similar to some of the rocks at the northern end of the Preacher granite which were interpreted as being gradational into feldspathic graywackes of the Calligan formation, it would appear that the Preacher granite could form a possible link between the Calligan formation of the map area and the Guye formation of the Snoqualmie quadrangle.

Faulting

The faults may be divided into three groups: those intimately associated with the regional folding, those near the boundaries of the granitic bodies and originating near the time of their emplacement, and finally, the more recent faults cutting all the rocks of the area.

The abundant faulting of the more brittle beds in the

PLATE 57



SKETCH SHOWING POSSIBLE STRUCTURAL EXPLANATION OF RELATION BETWEEN PREACHER GRANITE, QUARTZ CREEK COMPLEX, AND MT. GARFIELD VOLCANICS northwestern part of the area has been described. These faults have a general trend parallel to the strike of the strata.

The tight folding adjacent to the Snoqualmie granodiorite is accompanied by much faulting with the relative movement such that more room was provided for the invading granitic rock masses. These faults usually have a trend more or less parallel to the boundaries of the granitic bodies. Much faulting has occurred at the northern end of the Preacher granite, of which that along the Garfield fault described above is the most conspicuous. Some rocks of the neighboring Quartz Creek Complex have suffered extreme brecciation followed by recrystallization.

Within the Snoqualmie granodiorite in the northeastern part of the area are numerous faults ranging in strike from N60°W to N60°E. Locally they have lenses of quartz and sulphides along them and then they form some of the mineral deposits of the district. There are no marker beds which could provide a clue as to the relative movement, but its magnitude is believed to be small in most cases. In the lower adit on the Lennox vein grooves on the fault surface show that the latest movement was horizontal. These faults show a change in strike in the vicinity of Goat Mountain such that they tend to parallel the southern boundary of the granodiorite. They appear to be minor faults along the crest of the anticlinal uplift occupied by the granodiorite. While essentially parallel to one of the joint systems in the granodiorite, they do not stop at the boundary of the granodiorite. The fault along the Lennox vein can be observed extending into the Calligan formation on the ridge southwest of the Lennox River.

Many faults in the map area have no mineral growth along them and some of these are probably of quite recent age. One strongly marked fault cutting interbedded tuffs and shales of the Calligan formation is exposed along the logging road up Big Creek (cf Plate 58). Another conspicuous fault accompanied by much brecciation and gouge is exposed along the logging road above Quartz Creek where the logging company has excavated some of the brecciated rock along the fault for road surfacing. Numerous zones of sheeting consisting of numerous closely spaced parallel fractures can be observed in the more massive rocks, and these zones are usually parallel to the strongest system of jointing in the vicinity.

Jointing

Jointing is well developed in the Snoqualmie granodiorite but is not very conspicuous elsewhere. Some bare rock cliffs in Preacher granite several thousand feet high show little jointing and tend to form rounded surfaces. On the other hand, steep bare cliffs in Snoqualmie granodiorite are criss-crossed with joints.

The minor joint systems vary considerably in strike and dip and often appear to be parallel to the exposed surface of the ground. In contrast to the minor joints which vary in

PLATE 58

Photograph of fault cutting massive tuffaceous beds along the Big Creek logging road.

strike from outcrop to outcrop, there is a very persistent set of jointing in the main body of the Snoqualmie granodiorite striking in a general east-west direction, with steep dips to the south, and a weaker set of jointing in a general north-south direction, with variable steep dips. The faulting associated with these joint systems has been mentioned.

MINERAL DEPOSITS

History

No complete record is available of the prospecting activities in the area. The earliest work began in 1906 and 1907 when the first tunnels were driven on the prospects along Quartz Creek. Some prospecting was undoubtedly done along the North Fork of the Snoqualmie River at this time. The Bear Basin deposits were prospected quite thoroughly in the 1920's when a fifty-ton mill was constructed, but transportation facilities were poor and the operation was not a success. Activity in the district continued through the 1930's when considerable work was done on the Lennox property, aided by a mine to market road which was roughed out up the Snoqualmie North Fork as far as the Lennox River and allowed access by tractor and some trucks that far. There was lots of promotional activity and buying and selling of claims during this period but not much underground development work on the veins.

Activity in the district died down during the Second World War but was renewed in 1946. Since that time access to the deposits along the Snoqualmie North Fork has been greatly facilitated by the construction by the St. Paul and Tacoma

Lumber Company of a good logging road along the old mine to market right of way almost to the Lennox River. In 1949 and 1950 State of Washington mine to market road funds were used to construct a road from the end of the logging road, up the Lennox River to the vicinity of Bear Creek.

Production of metals from the district has been nil. A very small amount of hand sorted ore is said to have been taken to the Tacoma smelter from the Lennox property. Some ore was milled at the Bear Basin property and a few sacks of concentrate were found in the charred remains of the mill, which burned down, but little stoping was carried on in the mine so the production must have been very small.

Minerals and Paragenesis

Primary Minerals

The gangue minerals which are present in significant quantities are as follows:

Quartz	- Most abundant, almost always present
Calcite	- Minor, present in Lennox vein
Rhodochrosite	- Important at Bear Basin Silver vein only
Tourmaline	- Minor, present at Quartz Creek and on Jack Pot claims
Sericite	- Widespread alteration product of wall rocks; some present in most veins

Ore minerals which have been identified include the following: pyrite, arsenopyrite, pyrrhotite, chalcopyrite, jamesonite, sphalerite, galena, molybdenite, and scheelite-powellite. The presence of gold and silver has been shown by assays.

Paragenesis

Quartz was the earliest mineral to form. It is typically coarse grained and often occurs in euhedral crystals. A coarse crustification, which is better seen in the hand specimen than in thin section, is frequently present. Quartz continued forming throughout the metallization.

Calcite appears to be always later than quartz, and at the Lennox property some calcite veinlets also were observed filling fractures in pyrite. In the Bear Basin silver vein some quartz lining vugs is later than the rhodochrosite, while other quartz is earlier.

Pyrite was usually the first sulphide to form, but if arsenopyrite is also present they usually do not penetrate each other and may be essentially contemporaneous. In the Lucky Strike and Goat Mountain prospects some cross-cutting veinlets of sphalerite penetrating pyrite can be seen, and at the Langer property veinlets of chalcopyrite cutting sphalerite and pyrrhotite can be observed. Along Quartz Creek some outcrops of nearly pure arsenopyrite in quartz contain very small cross-cutting veinlets and irregular grains of chalcopyrite. In the Goat Mountain prospect the small amount of galena present was later than the pyrite and spalerite. In the Bear Basin Alex vein jamesonite can be seen replacing both pyrite and chalcopyrite. No silver minerals or gold were identified.

The succession of sulphide minerals is thus seen to be as follows:

Pyrite	Often contemporaneous
Arsenopyrite	
Pyrrhotite	
Sphalerite	
Chalcopyrite	
Jamesonite	No criteria for relative position
Galena	

This sequence is not unusual as it is in accord with that observed in most mining districts where these minerals are present.

<u>Types and Distribution of Mineral Deposits</u>

The mineral deposits may be put into two main groups, those within the Snoqualmie granodiorite and those occurring elsewhere. The veins within the Snoqualmie granodiorite include the following:

Bear Basin Silver Vein - Silver-bearing jamesonite in rhodochrosite

Bear Basin Alex Vein	- Base metals with some gold and silver
Jack Pot Prospect	- do
Goat Mountain Prospect	- do
Lucky Strike Prospect	- Arsenopyrite-pyrite-quartz vein with gold and silver
Beaverdale Prospect	- do
Lennox Vein	- do
Devils Canyon Prospect	- Molybdenite in quartz

The following deposits occur outside the Snoqualmie granodiorite:

Langer and Rainbow Claims	- Pyrrhotite, chalcopyrite, sphalerite veins in hornfels
Quartz Creek Prospect	- Copper replacement deposits in quartz diorite

The mineral deposits in the Snoqualmie granodiorite which are listed above are all found in the large mass of this rock in the northeastern part of the map area. An old tunnel along Granite Creek in the Snoqualmie granodiorite occurring in the southwestern part of the area has traces of copper minerals on the dump but the tunnel was caved and could not be entered.

All the veins in the northeastern part of the area strike in the same general direction. The mineralogy varies from vein to vein. Some of the faults are quite persistent but the ore occurrences are restricted to lenticular shoots along the faults where structural conditions were favorable for the maintenance of open spaces. In some cases the veins have been opened by further movement as evidenced by the fracturing of early pyrite and quartz and the filling of these fractures or replacement along them by later minerals.

Mineralogically the veins show considerable variation. Within a few miles in the northeastern part of the map the nearly parallel veins all in granodiorite show molybdenite at Devil's Canyon, sphalerite and pyrite at the Jack Pot Claims, silver bearing jamesonite in rhodochrosite at Bear Basin, and arsenopyrite and pyrite in quartz at the Lucky Strike and Beaverdale prospects.

The Lennox vein is in a quartz diorite migmatitic border phase of the Snoqualmie granodiorite along the Lennox River and is similar in mineralogy and structure to some of the veins in the Snoqualmie granodiorite. The mineralization on the Langer and Rainbow claims falls within hornfelsized sediments of the Calligan formation within a short distance of the contact with the Snoqualmie granodiorite. Not much faulting occurs with these veins in hornfels and they are essentially replacement deposits with such high temperature gangue minerals as garnet, plagioclase feldspar, and amphiboles.

The other deposit outside the Snoqualmie granodiorite is along Quartz Creek in the quartz diorite complex. This area shows outcrops at three locations within a distance of one-fourth mile, all with different mineralogy. The principal values are in copper which occurs principally as chalcopyrite. At the three locations mentioned above the chalcopyrite occurs with considerable pyrite, arsenopyrite, and molybdenite, respectively. The deposit represents a replacement in a brecciated zone, although locally some filling has occurred. Gangue minerals include quartz, sericite, chlorite and tourmaline.

Description of Individual Deposits

General Features of Bear Basin Deposits

The Bear Basin Mining Company has a group of twenty-five mining claims in the basin drained by Bear Creek. Several nearly parallel veins of two distinct types have been prospected by about 1750 feet of drifting and cross-cutting.

Bear Basin is typical of the basins shaped by local alpine glaciation, with Bear Creek following a step-like ascent. At about 4200 feet elevation the valley widens out to an amphitheatre-shaped basin surrounded by nearly vertical rock cliffs about five hundred feet high. Talus slopes composed of large blocks of granodiorite have accumulated around the foot of these cliffs. Above the cliffs the slopes become more gentle with two small depressions occupied by Bear Lakes, and finally steepen again to culminate in ridges at an elevation above 5000 feet. The veins outcrop in the cliffs above 4200 feet elevation and being accompanied by faulting and alteration and generally softer than the wall rocks, form the paths for water from the melting snow on the upper slopes.

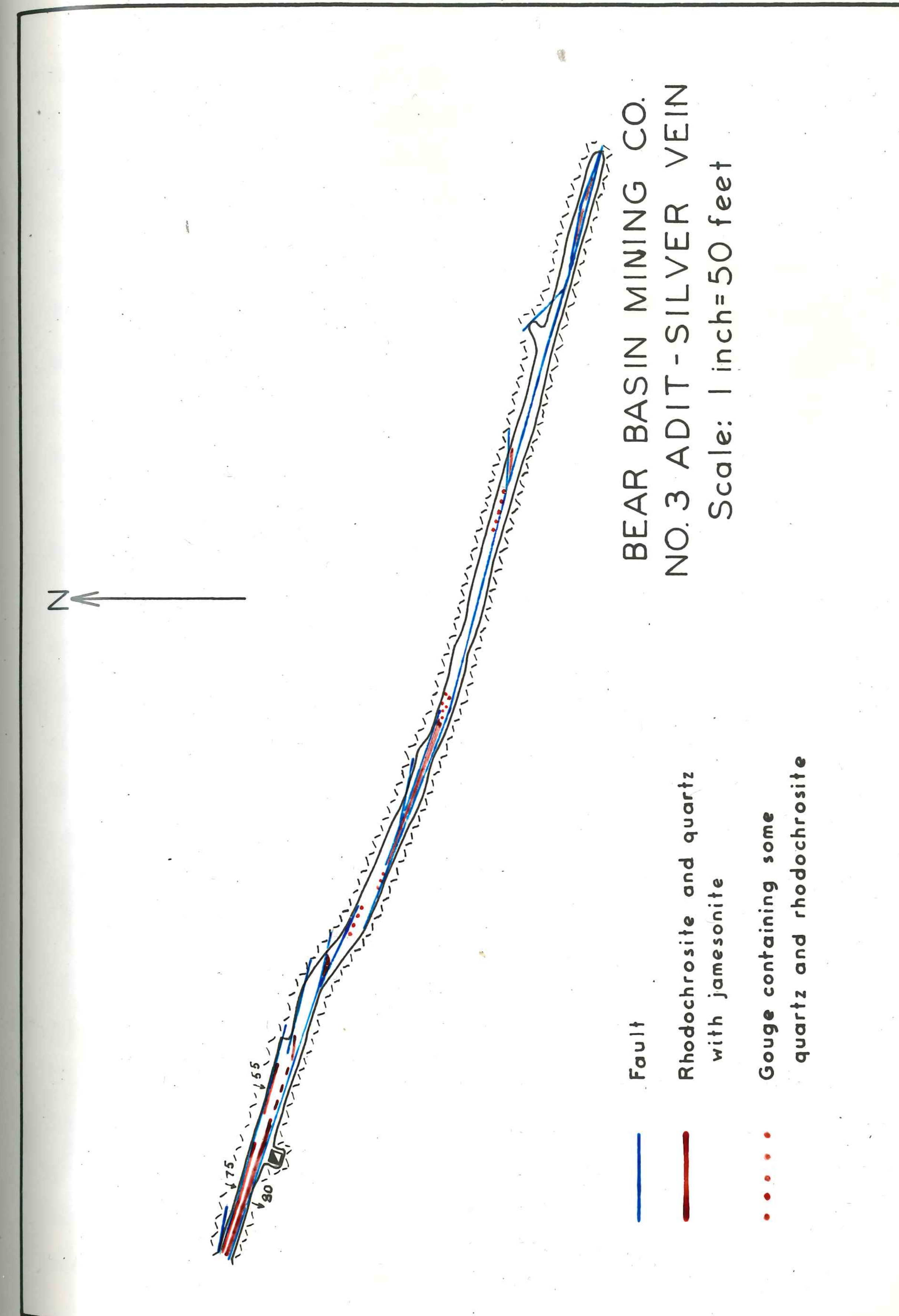
Prospecting adits have been driven into the cliffs on the veins at the top of the talus slopes. From south to north these adits are: the number three which is driven some 450 feet on the Silver vein, characterized by banded quartz and rhodochrosite with silver bearing sulphides of lead and antimony; the numbers four, five, and eight adits which prospect zones marked mainly by brecciation and alteration of granodiorite; and adits numbers six and seven which cross-cut the Alex vein, marked by strong faulting and some iron, copper, lead and antimony sulphides. Since the mineralization in the Silver and Alex veins is noticeably different they will be treated separately.

Bear Basin Silver Vein

Structure

The vein outcrops in a small ridge between two talus slopes. It is well exposed in an open cut and shows two faults five feet apart striking S73°E and dipping steeply to the south, with a foot of banded quartz and rhodochrosite on each wall, separated by three feet of brecciated and altered granodiorite. Immediately below the west end of this open cut a drift was begun and follows the vein in an easterly direction for 450 feet. The vein, as seen in Plate 59, is

PLATE 59


BEAR BASIN MINING CO.
NO. 3 ADIT-SILVER VEIN
Scale: 1 inch=50 feet
N
75
55
80
Fault
Rhodochrosite and quartz with jamesonite
Gouge containing some quartz and rhodochrosite

marked by a rather strong faulting in the plane of the vein. Except for a slight echelon at the bend in the drift one hundred feet from the portal the fault along the south or hanging-wall side is nearly continuous and is marked by considerable gouge and has a nearly uniform dip of eighty degrees to the south. At several places along this vein, faults with a strike of about S78°E and dips which are generally less than eighty degrees approach this hanging-wall fault from the north or foot-wall side.

Both along the intersecting faults and along the hanging-wall fault near the intersection with these faults are varying thicknesses of pink banded rhodochrosite and clear banded, and in places vuggy, quartz. In the rhodochrosite are irregular shaped grains of sulphides, mostly the silver bearing lead-antimony sulphide, jamesonite. At the portal the foot-wall fault and hanging-wall fault are nearly parallel, both in strike and dip, and about forty-two inches apart, with rhodochrosite and quartz fifteen inches wide next to the footwall fault and twelve inches wide on the hanging-wall side, separated by fifteen inches of altered granodiorite. Following the foot-wall fault eastward along the drift its dip becomes less and it separates more and more from the hanging-wall fault and in so doing the amount of rhodochrosite and sulphides along it decreases until at one hundred feet from the portal the foot-wall fault is quite weak and there is no longer any rhodochrosite.

At 220 feet from the portal another fault striking

S78°E intersects the hanging-wall fault and there are eight inches of rhodochrosite and quartz over a length of fifty feet where the two faults are fairly close together.

The vein thus presents the pattern of a rather persistant shear, represented by the hanging-wall fault, along which are zones of tension fractures which intersect the shear at a small angle, and the banded quartz and rhodochrosite, containing the ore minerals, have been deposited in tensional openings near these intersections.

Mineralogy of the Silver Vein

The mineralogy of the silver vein is quite simple. The main gangue mineral in the vein is rhodochrosite, which is light pink in color, and delicately banded, usually symmetrical with respect to small openings, some of which still exist. The banding is partly due to a variation in grain size of the rhodochrosite, evidently due to a rhythmic changing of physical conditions, and partly due to the inclusion of some quartz and sulphide bands.

Some small openings parallel with the vein walls still exist and these are usually lined with fine druzy quartz crystals which are later than the rhodochrosite. The rhodochrosite shows some beautiful cockscomb structures (cf Plate 60). Some fractures in this banded rhodochrosite have been filled with later quartz.

The chief ore mineral is the gray feathery lead sulphantimony mineral jamesonite. This jamesonite appears to

PLATE 60

Photomicrograph of banded rhodochrosite from Number 3 adit, Bear Basin Mining Company, showing cockscomb structure. (Plain light; x 12) have been deposited along with some late quartz, as there is usually some quartz associated with the jamesonite, and in some cases jamesonite and druzy quartz occur together along small openings. Very locally the vein has suffered from later fracturing and reopening as some quartz and rhodochrosite show undulating extinction and fractures. Still later jamesonite and quartz have been deposited along these fractures. In contrast to the scattered feathery aggregates of jamesonite, this later jamesonite is in long narrow veinlets.

Other sulphides are sparingly present in the vein filling, usually in small scattered grains. These are sphalerite, pyrite, arsenopyrite, and chalcopyrite.

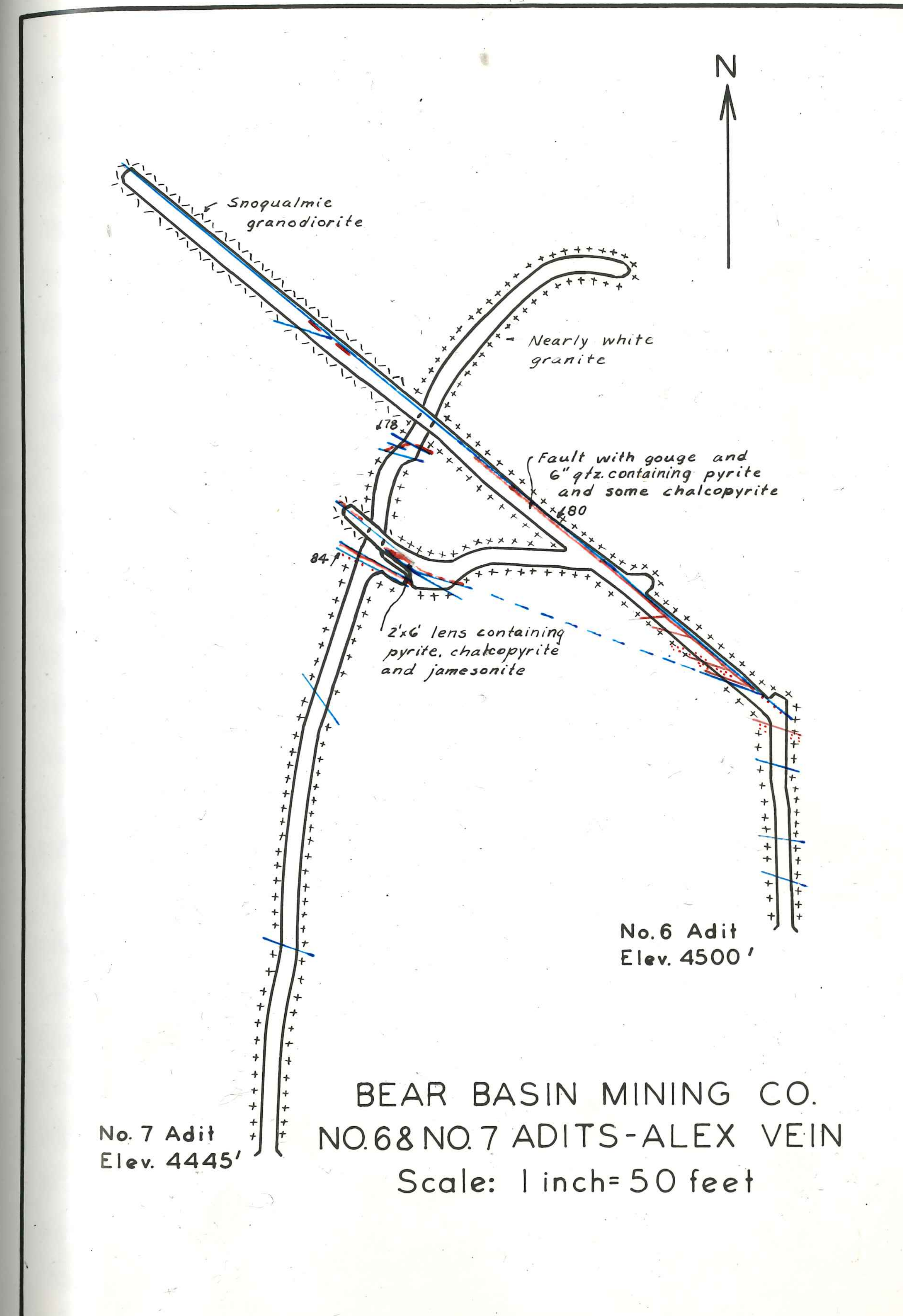
Bear Basin Alex Vein

Structure

The Alex vein outcrops in the cliffs on the north side of Bear Basin on the trail leading from the lower basin up to Bear Lakes. Two adits have been driven to intersect this vein at depth. The upper one, called number six adit, starts as a cross-cut at an elevation of about 4500 feet, about one hundred feet below the outcrop, while the other, called number seven adit, cross-cuts the vein about fifty-five feet lower and two hundred feet west of the number six portal.

The structure of the Alex vein, as seen in Plate 61, consists of two parallel faults, a foot-wall and hanging-wall fault, about fifty feet apart, joined in the vicinity of the

PLATE 61


N
Snoqualmie granodiorite
Nearly white granite
78
Fault with gouge and 6" qtz. containing pyrite and some chalcopyrite
80
84
2'x6' lens containing pyrite, chalcopyrite and jamesonite
No. 6 Adit
Elev. 4500'
No. 7 Adit
Elev. 4445'
BEAR BASIN MINING CO.
NO.6 & NO.7 ADITS-ALEX VEIN
Scale: 1 inch = 50 feet

number six adit by a diagonal fracture zone, making an angle of about twenty-five degrees with the parallel faults. Along this diagonal fracture zone, and near its junction with the foot-wall and hanging-wall faults, there has been considerable brecciation and alteration of the granitic rock and the deposition of irregular seams and pockets of sulphides. In addition there has been some deposition of sulphides along the parallel faults themselves as seen on the map.

The number six adit, after passing through several weak faults and some weak mineralization, intersects the strong foot-wall fault eighty feet from the portal. The hanging-wall fault evidently weakens before reaching this far east. This foot-wall fault, striking S51°E and dipping about 72° to the southwest has been drifted on for a distance of 325 feet to the northwest. It is a very straight fault with some gouge, and for 150 feet from where it is cross-cut by the number six adit it has along it four to six inches of black sulphides with some green copper staining. Starting twenty feet west of the cross-cut this fault is intersected by the diagonal fracture zone consisting of a series of fractures striking S75°E and spaced several feet apart. Along these fractures are some two to six inch wide veinlets of black sulphides, and the intervening wall rock is brecciated, altered, and has numerous irregular veinlets and pockets of sulphides. These sulphides leave a black streak when the soft rock is hit with a pick. These intersecting faults are not encountered beyond sixty feet from the cross-cut and from there to the end of the drift this foot-wall fault is very straight and the sulphides only occur locally adjacent to the fault, the fault being mainly marked by a narrow gouge.

Along the drift at a point one hundred feet west of the number six adit cross-cut another cross-cut leads off diagonally to the west. At approximately sixty feet from the drift it reveals another shear striking S52°E to S62°E, or nearly parallel to the main foot-wall fault, but fifty feet south of it, and nearly vertical. At the place where this cross-cut first encounters this hanging-wall fault it is seen that there is some transverse fracturing between this fault and the foot-wall fault, which lines up with the intersecting fractures and sulphide seams encountered in the main drift and described above.

Wall rock in the vicinity of the Alex vein
and its influence on the structure

There are two types of granitic rock exposed in the number six adit. As seen on the geologic map (cf Plate 70), Bear Basin falls within the large body of the Snoqualmie granodiorite. This granodiorite is the wall rock of the Silver vein and occurs throughout most of the area. However, within this granodiorite are some areas of light colored rock, lower in mafics and higher in quartz and potash feldspar than the granodiorite. These lighter colored rocks are believed due to the work of potash metasomatism enriching the rock in potash and silica at the expense of iron and magnesium, and producing a rock which is in reality a granite rather than a granodiorite.

The Snoqualmie granodiorite in the Bear Basin district as examined in thin section shows large subhedral grains of andesine feldspar, twenty per cent quartz in irregular grains, twenty per cent orthoclase in anhedral poikilitic plates, plus about ten per cent hornblende and ten per cent biotite. The hornblende is partly in euhedral grains. The biotite forms large plates with ragged borders and is partly altered to chlorite, and partly to a peculiar green biotite. The latter is strongly pleochroic, pale brown to bright green. Also present are some grains of tourmaline, zircon, apatite, and some of the plagioclase has altered with the formation of epidote, sericite and calcite.

In contrast to the granodiorite the light colored granitic rock shows the effect of potash metasomatism. Only a few pieces of plagioclase feldspar remain as skeleton crystals surrounded by the quartz, calcite, and orthoclase which have replaced it. The rock is composed of about fifty per cent quartz, thirty per cent orthoclase, five per cent plagioclase, ten per cent calcite, and some sericite and pyrite, and can be called a granite. This potash and silica metasomatism which produced the granite from the granodiorite is earlier than the formation of the Alex vein and not the result of the ore bearing solutions, as it will be seen that the faulting pattern changes on passing from the granodiorite to the granite. This same leucocratic granitic rock occurs at other spots in the basin not immediately adjacent to veins.

The contact between the granite and granodiorite is visible in the number six tunnel, running roughly north and south. It evidently dips at a low angle to the west as the hanging-wall drift of the number six adit level is in granodiorite near its west end, while fifty feet vertically below, the number seven cross-cut is in granite. Since the diagonal fracturing and sulphide mineralization discussed above appear to start where the hanging-wall or south fault passes out of the granodiorite and into the granite, it appears that the change in competency of the wall rock has affected the fracture pattern.

Mineralogy

The granite and granodiorite walls of the vein are at some places fairly fresh to within a few inches of the hanging-wall and foot-wall faults. In the vicinity of the diagonal fracturing, where the mineralization has been strongest, the granite has been highly altered to a white aggregate of quartz and muscovite with disseminated pyrite. The muscovite occurs in small radiating plates between the quartz grains and sometimes penetrating the grains.

In the four to six inch wide veinlets the sulphides occur with quartz. In the diagonal shear zone some bunches and isolated grains of sulphides occur in the highly altered and brecciated granite. The quartz is fairly coarse grained and crustification is absent. The granular quartz is crossed by numerous lines of fracturing along which the quartz is deformed and shows microbrecciation.

Pyrite is by far the most prevalent sulphide, and forms along fractures in the quartz, mainly by replacement. It occasionally forms cubes, but irregular outlines are more common. Where it has been fractured and pulverized by later movements it is friable and appears as a streak of black sulphides. A much smaller amount of chalcopyrite occurs as irregular grains scattered through the quartz or is occasionally seen replacing pyrite. This chalcopyrite is partly altered to malachite or azurite where exposed to the air in the drift or to circulating water along fractures.

In the short hanging-wall drift of the number six adit there is a pocket of sulphides about two feet wide by six feet long which seems to have arisen in a small diagonal fracture having a pattern suggesting a tensional fracture. Within this pocket some gray feathery jamesonite has been deposited along with pyrite and chalcopyrite, and this pocket produces some values in silver. A polished section of sulphides from the pocket mentioned above shows an elongated oval of sulphides containing about equal amounts of chalcopyrite and jamesonite in the center with an outer ring of pyrite. Within the jamesonite is a small cavity, suggesting the possibility of some filling of open spaces. At other places in the same specimen the jamesonite appears to have formed by replacement, and was the last mineral to form, replacing both pyrite and chalcopyrite.

A few grains of arsenopyrite are present. It appears to be contemporaneous with the pyrite. The early pyrite shows more fracturing and brecciation than the chalcopyrite, while one area of jamesonite about one centimeter long shows no fracturing, indicating that the shearing diminished during the later part of the metallization. Some fractures in the pyrite are filled with cryptocrystalline quartz with a low index of refraction suggesting that temperatures decreased during the last stages of mineralization.

Goat Mountain Prospect

Goat Mountain is the 5600 foot peak located southeast of Sunday Lake. On the west side of this peak, about one mile south of Sunday Lake, a fault zone is exposed between 3000 and 3700 feet elevation in a rather narrow canyon. The owner, Robert Prufer, has a cabin and blacksmith shop along Sunday Creek near the vein. There has been no development to date, but the vein in the canyon has been prospected by blasting numerous open cuts across the canyon floor.

The wall rock is Snoqualmie granodiorite. The lowest exposure of the vein in the canyon near 3000 feet shows a fault near the south wall of the canyon striking N90°W, with some gouge along it. North of this fault is a five inch seam of sulphides consisting mainly of pyrite, but some arsenopyrite and sphalerite are present. To the north of the sulphides are five feet of brown altered granodiorite, and then a granodiorite wall striking N70°W or at an angle of about twenty degrees to the fault on the south wall. This structural pattern is repeated on up the canyon to the east with a fault continuing fairly strong for several hundred feet and then fading out while another fault either parallel or at a small angle, and often on the opposite wall of the canyon, will become fairly strong for a few hundred feet until it too is superseded by still another fault. In this manner the fault zone continues for a length of about 1000 feet.

Likewise, the seams of quartz and sulphides are not continuous, but are somewhat lenticular and scattered at intervals along the canyon, usually immediately adjacent to one of the faults. No exposure of sulphides can be followed for over twenty feet along its strike because of limited exposures in the floor of the canyon. The widest quartz-sulphide seam observed was about six inches, but Mr. Prufer reports one seam fourteen inches wide was exposed in an open cut which was covered by slides when this property was visited. Pieces of quartz containing pyrite and sphalerite supposed to have come from this seam were lying beside this open cut and were similar to the sulphides from smaller seams observed elsewhere in the canyon.

From 250 to 300 feet east of the first outcrop at 3000 feet elevation, the creek follows the north wall of the canyon and exposes occasional one to five-inch quartz stringers with some pyrite, sphalerite and a few grains of galena and chalcopyrite. About two hundred feet farther east a fault on the south side of the canyon shows some gouge and one to four inches of quartz and sulphides along it. Additional quartz-sulphide seams are exposed at 3400 feet elevation and again at 3700 feet. At this uppermost exposure well defined firm walls of granodiorite nineteen feet apart bound a fault zone showing brecciated and altered granodiorite and at one spot within it, two two-inch quartz-sulphide seams separated by six inches of gouge containing some quartz and sulphides. The paragenesis is pyrite, arsenopyrite, sphalerite, chalcopyrite, and galena.

Jack Pot Prospect

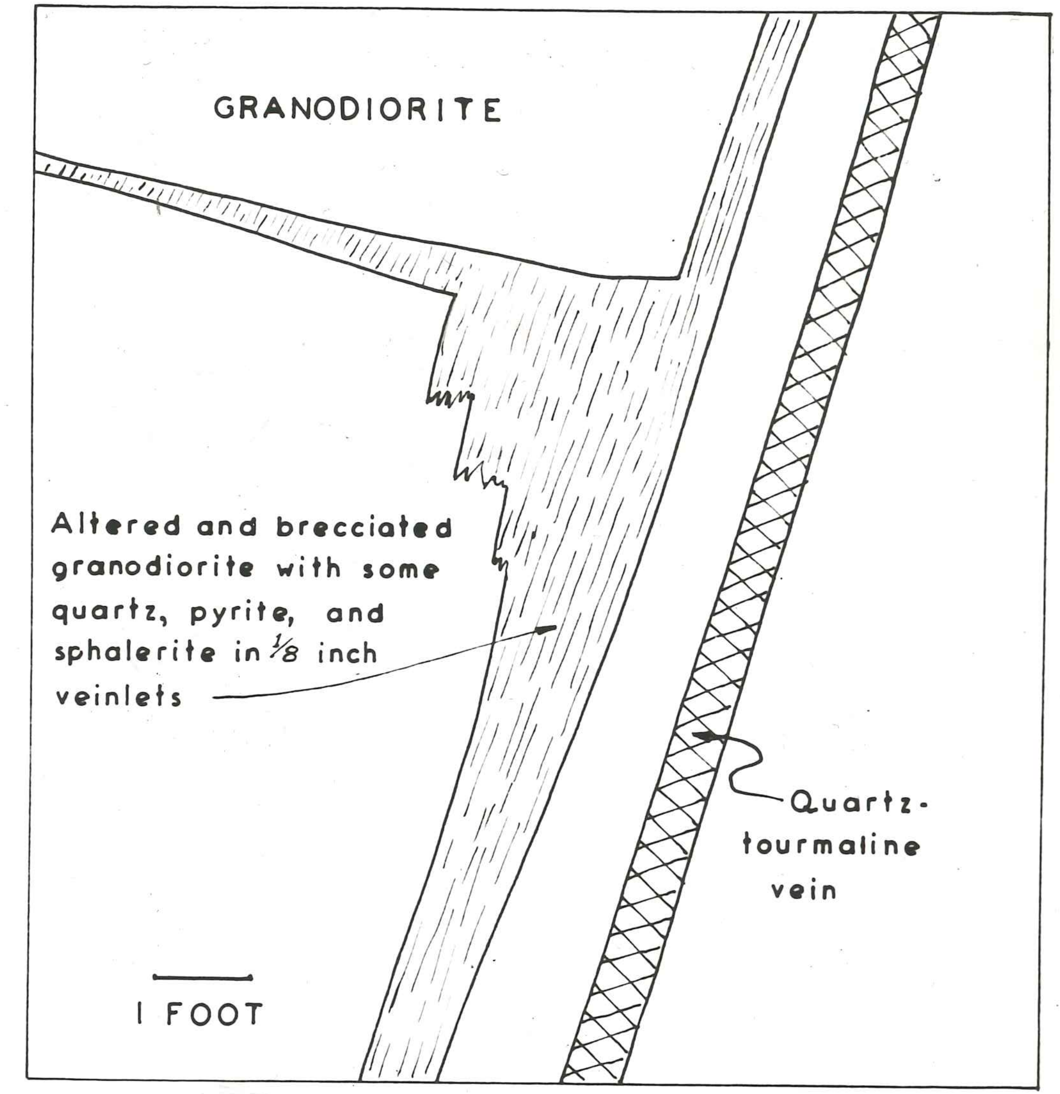
On the north and east side of Goat Mountain are some fractures which locally contain values in gold, silver and zinc. These fractures follow approximately along a line but are not continuous. The mineralized fractures have nearly the same strike as the direction of best developed jointing in the granodiorite. The mineralization frequently ends at a cross joint.

The greatest metallization is on claim number one where a vein is exposed at 4740 feet elevation in the nearly vertical face of a cliff on the east side of a large basin below Goat Mountain. The vein is lenticular in vertical section, varying from two feet wide near the top of the cliff to about ten feet wide at fifty feet lower elevation. Forty feet farther down the slope in line with the vein some massive granodiorite partly exposed beneath the talus shows that the vein has again narrowed. At its widest part the vein shows from south to north the following detail: a fault striking N78°E and dipping eighty degrees south; four inches of quartz; sixteen inches of brecciated and bleached granodiorite; five inches of quartz with considerable sphalerite and pyrite; twelve inches of granodiorite; four inches of quartz with sphalerite and pyrite; two feet of soft brecciated granodiorite; six inches of quartz with some quartz druzes; three feet of soft brown granodiorite with some scattered sphalerite and pyrite grains; six inches of brecciated quartz with criss-crossing veinlets up to one-half inch wide of sphalerite.

About eight hundred feet to the west of the above exposure another outcrop shows the close association of the sulphide mineralization with jointing and also with the tourmaline veinlets which are found at numerous spots throughout the granodiorite on Goat Mountain (cf Plate 62). Here mineralization ends at a cross joint and a five-inch quartz-tourmaline veinlet parallels the vein.

At another point on the east slope of Goat Mountain about 1100 feet from Cougar Creek and more or less in line with the above outcrops a vein is exposed in a small canyon. At 3600 feet elevation in the floor of this canyon the vein is two feet wide and shows twelve inches of gouge containing

PLATE 62



This sketch of a small vein containing some values in zinc, gold and silver, which outcrops on the Jack Pot claims, illustrates how mineralization frequently diminishes at a cross joint. The tourmaline veinlets are quite common on Goat Mountain.

brecciated quartz with some black streaks of crushed sulphides, six inches of quartz, and six inches of silicified granodiorite. Some irregular seams of sulphides two to three inches wide occur in the quartz. The chief sulphide is pyrite but some sphalerite and small amounts of chalcopyrite and scheelite are present.

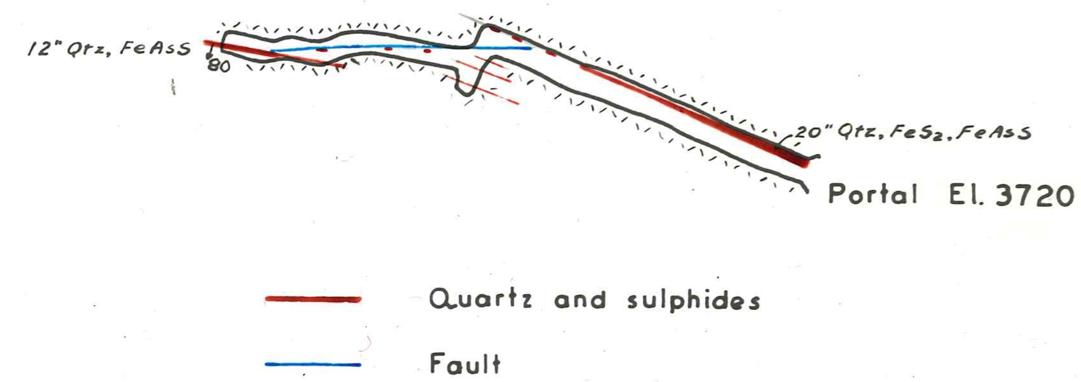
Lucky Strike Prospect

This property is located in Sections 9 and 10, Township 25 North, Range 10 East, on the slope south of the North Fork of the Snoqualmie River between 3000 and 4000 feet elevation. Development consists of a winze approximately thirty feet deep. The trail to the prospect leaves the North Fork trail about three and one-half miles above the mouth of the Lennox River and climbs for about two miles to the location of the winze.

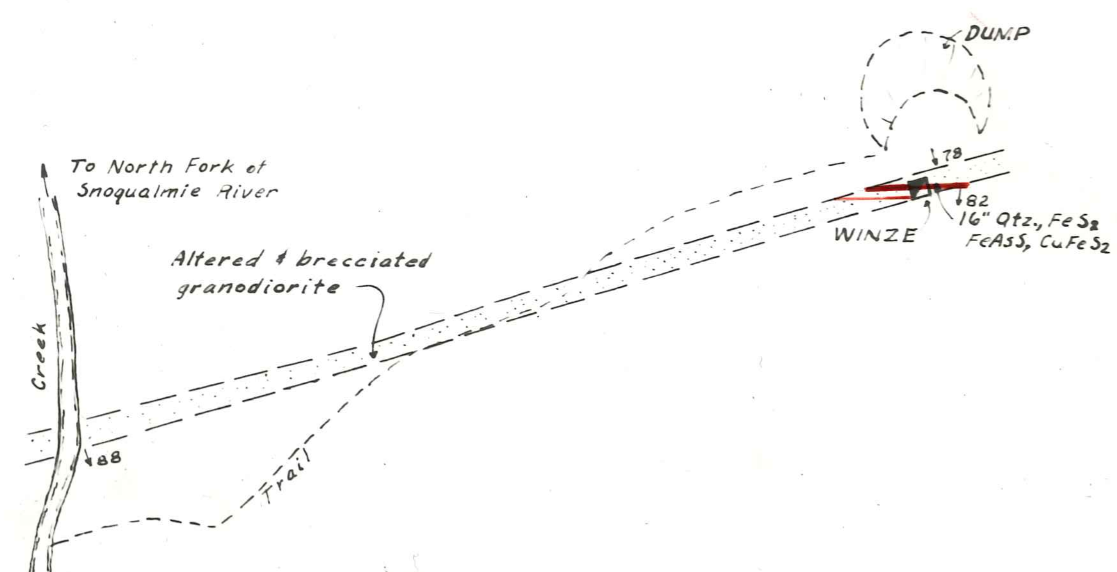
The country rock in the vicinity of the vein is Snoqualmie granodiorite. The vein consists of two parallel faults about six feet apart, striking N73°E and dipping 78 degrees to the south (cf Plate 63). The granodiorite between the faults is brecciated and altered to a light colored aggregate of quartz and sericite, with considerable pyrite disseminated through it.

During the shearing along the vein there was produced some diagonal tensional fractures between the hanging-wall and foot-wall faults, and which make an angle of about sixteen

PLATE 63



UPPER BEAVERDALE TUNNEL
Scale: 1 inch = 40 feet



LUCKY STRIKE PROSPECT
Scale: 1 inch = 50 feet

degrees with the strike of the main vein. Some coarse grained quartz and finer grained sulphides have been deposited along these transverse fractures. The winze has been centered on one of these bands of quartz and sulphides which varies in thickness from twelve to sixteen inches.

The owners, George and Gary Rutherford, have blasted the over-burden from the vein at the surface just west of the winze. Here the principal sulphide seam is twelve inches wide. A few other parallel quartz and sulphide seams one inch wide and one sulphide seam three inches wide are contained in the remaining five feet of altered granodiorite between the vein walls.

Mineralogy

The quartz in the veinlets is coarse grained, with elongated crystals perpendicular to the walls of the veinlets. Interstices between the larger crystals are filled with smaller quartz crystals and some arsenopyrite and pyrite. Some small openings lined with projecting quartz crystals and sulphides still exist.

In some places the transverse seams are composed of almost solid sulphides. The earliest and most abundant sulphides are pyrite and arsenopyrite in that order. Within the quartz veinlets the sulphides appear to have formed largely by precipitation in openings between quartz grains. Sometimes a crude crustification can be observed. The third most abundant sulphide is chalcopyrite, which occurs as small grains in the quartz, mostly along small microfractures, and as irregular grains in the sulphide seams replacing both arsenopyrite and pyrite. A polished section from the sulphide seam on the east side of the winze sixteen feet from the top shows some pyrite cubes surrounded by arsenopyrite, with irregular grains of chalcopyrite replacing both pyrite and arsenopyrite.

The principal values are in gold and silver, which occur mainly in the transverse quartz and sulphide seams within the vein. On the basis of available assays the ratio of gold to silver averages about one to seventeen.

Where the vein is exposed in a small creek 250 feet west of the winze the alteration of the granodiorite is less intense. There are a few quartz veinlets an inch wide in the altered zone but almost no sulphides. The vein is not exposed on the timbered slope to the east of the winze.

Beaverdale Prospect

Location and Structure

This property is located on Illinois Creek, which enters the North Fork of the Snoqualmie River in the northeastern part of the area. Along Illinois Creek at an elevation of 3000 feet an old log cabin, partly fallen in, is all that remains of the old mine camp. The vein outcrops along a narrow canyon which enters Illinois Creek from the west about 1000 feet up Illinois Creek from the cabin. A tunnel, now caved, has its portal on the north side of the canyon at 3370 feet elevation, in the talus slope.

Up the canyon from the lower tunnel is another tunnel fifty-five feet long with its portal in the north wall of the canyon at 3610 feet elevation. Still farther up the canyon, at 3720 feet elevation, is a tunnel which follows along the vein for 140 feet (cf Plate 63).

The country rock is Snoqualmie granodiorite. The deposit consists of a narrow zone of faulting, along which the granodiorite is brecciated and altered. This zone is not a continuous fault, but is a series of relatively short faults along a zone, with one fault weakening while another fault continues along the strike of the fault zone, with sometimes a diagonal fault connecting the two as seen in the map of the upper tunnel. At some places along this zone some quartz and sulphides, from a few inches up to twenty inches in width, presumably containing values in gold and silver, have been deposited.

Mineralogy

The Snoqualmie granodiorite at this prospect is almost a quartz monzonite, with a mineral composition of thirty-five per cent andesine feldspar, thirty per cent anhedral orthoclase and microperthite, twenty per cent quartz, and fifteen per cent biotite and chlorite in ragged plates.

The dump outside the portal of the lower tunnel shows both fresh granodiorite and soft brown altered granodiorite containing some disseminated pyrite. At the side of the portal is a pile of soft yellow stained brecciated quartz with visible pyrite, some in the form of small cubes, and some streaks of soft black crushed sulphides. These soft black sulphides are mainly arsenopyrite, but also include some brecciated pyrite, and some small irregular sheared grains of soft gray sulphide, probably galena.

In the fifty-five foot tunnel at 3610 feet elevation the vein strikes N80°W and dips 78 degrees to the south. It shows the following detail from north to south: twelve inches of soft gouge, sixteen inches of soft altered and brecciated granodiorite, and sixteen inches of quartz and sulphides. The quartz is granular, and the chief sulphides are pyrite, in grains one to two millimeters in size, and finer grained arsenopyrite.

In the portal of the upper tunnel at 3720 feet elevation (cf Plate 63) are twenty inches of brownish yellow stained, rather porous quartz, containing pyrite and arsenopyrite. This quartz and sulphide portion of the vein, which is twenty inches wide at the portal, narrows to ten inches at thirty feet from the portal, and to six inches at fifty feet from the portal. At eighty feet from the portal the vein pinches out and the drift turns and follows a diagonal fault to another quartz-sulphide vein en echelon to the first. The face of the drift along this vein shows twelve inches of quartz and sulphides, and twelve inches of soft altered granodiorite containing some one-fourth to one-half inch criss-crossing veinlets of sulphides. The chief sulphide here is arsenopy-

The lode cuts across a rather wide contact zone between the Snoqualmie granodiorite and the tuffaceous sediments and tuffs to the south. The eastern end of the lode as exposed in the low level cross-cut is in a rather fine grained quartz diorite which occurs in this contact zone. This quartz diorite is much finer grained and fresher appearing than the normal granodiorite, and in many places shows marked allignment of its elongated feldspar laths (cf Plate 53). In places it is actually a migmatite, containing irregular patches of coarser grained more leucocratic rock.

Structure

The structure of the Lennox lode is best described as a mineralized fault zone. The principal fault is usually on the south or hanging-wall side of the fault zone, and in the western end of the lode, where the structure is best exposed, the ore occurs mainly as seams rich in sulphides which occur in subordinate fractures in the country rock near the principal fault but usually at a slight angle to it.

Exposures along the vein

The most westerly, and also the uppermost, exposure along the vein is at an elevation of 2700 feet where the vein occurs in the floor of a steep canyon leading up from the Lennox River. Some of the earlier workers have blasted the over-burden from the vein. The fault zone here is about twelve feet wide. The hanging-wall is marked by a fault, striking S76°E, dipping fifty degrees to the south, with a soft gouge containing scattered veinlets of sulphides. The foot-wall side of the vein is a fault striking S87°E, or at an angle of eleven degrees with the hanging-wall fault. Along this foot-wall fault are four feet of hard bluish quartz with disseminated pyrite and arsenopyrite. On the out-crop this quartz has a greenish yellow and a black stain. It is reported to carry values in gold. This quartz ends and the fault on its north side fades out as the distance from the principal fault increases, so that it has a rather lenticular shape. From this open-cut the principal fault continues down the center of the steep canyon to the east and is marked chiefly by a gouge. The hanging-wall of the vein next to the principal fault is highly altered and consists mainly of sericite and quartz with some inch-wide black seams of finely divided pyrite.

The next place where some development work has been done is about 150 feet east and 140 feet lower than the open-cut described above. The principal fault in the open-cut at 2700 feet elevation has continued down the center of the canyon but is quite weak here and nearly vertical. A twenty-six foot long tunnel has been driven on a subördinate fault fifteen feet north of the canyon and approaching the fault in the canyon at a very small angle. Fairly fresh quartz diorite occurs between these two faults. On the south wall of this tunnel, at the portal, there is exposed a flat seam of massive sulphides one foot wide. Pyrite is the most abundant mineral, but arsenopyrite and sphalerite are also prominent. This seam dips at thirty-five degrees as compared with a dip of seventy-seven degrees for the fault in the tunnel, and appears to be a filling of a diagonal tensional opening in the diorite between the fault in the tunnel and the principal fault in the canyon. Ten feet from the portal of the tunnel the seam approaches the fault in the tunnel and narrows to six inches in width. Some of this heavy sulphide ore has been stock-piled outside the portal and is reported to carry good values in gold.

Another tunnel was started in the canyon wall about eighty feet east and fifty feet lower in elevation than the above tunnel. About thirty feet from the portal it encounters a weak fault with about two inches of pyrite along it, and follows it to the west. No larger seams of sulphides were encountered along this fault and 110 feet from the portal the drift was turned sharply to the south and at approximately ten feet from the fault which the drift had been following it encountered a one foot seam of massive sulphides and six inches of brecciated quartz. This is about fifty feet below and thirty feet west of the sulphide seam in the twenty-six foot tunnel described above, and they may be the same.

The canyon which has been following a course along the easily eroded fault zone now leaves the line of the vein and drops down to the Lennox River. Which, if any, of the faults exposed by the upper tunnels continues out of the canyon toward the east is not known, but on the timbered slope in line with the upper portion of the vein and 370 feet farther east from these upper tunnels are two old tunnels, now caved. One appears to be a drift and the other a cross-cut which intersect about twenty feet from their portals. No ore was visible on the dumps.

At a point 130 feet farther east, along the same line, at an elevation of 2210 feet, there is another old tunnel, now partly caved, but which can be entered on hands and knees. It follows along a fault in quartz diorite and reveals six inches of gouge and some disseminated sulphides in the brecciated and altered wall rock. A six inch wide quartz vein dipping at a low angle follows the north wall of the drift for a short distance.

The next exposure along the Lennox vein is in another small canyon which leads up from the Lennox River. Here an open cut blasted out of the east wall of this canyon exposes a strong fault striking N87°E and dipping fifty-two degrees to the south. On the foot-wall side of this fault are twenty-six inches of quartz and some calcite, with the eighteen inches nearest the fault showing considerable brecciation. The six inches of quartz adjacent to the fault contains a considerable amount of sulphides, mostly pyrite and arsenopyrite. The vein exposed in this open cut is said by the present operators to contain values in gold.

The long cross-cut being driven by the Priestley Mining and Milling Company intersects the vein at about 1900 feet elevation about two-thirds of the way between the open-cut described in the preceding paragraph and the caved tunnel at elevation 2210 feet. The vein as exposed in the cross-cut shows strong faulting and considerable quartz and some calcite, but no massive sulphides. On the west wall of the cross-cut the vein is twelve feet wide and shows the following detail in passing from the north or foot-wall side of the vein toward the hanging-wall side:

F.W. to 1'	Coarse grained massive quartz with some vugs lined with later calcite.
1' to 5'	Altered diorite, with much disseminated pyrite and some quartz veinlets.
5' to 6'	Inter-grown quartz and calcite.
At 6'	Strong fault striking N90°E and dipping 58 degrees south, with slickensides on which grooves indicate the principal movement was horizontal.
6' to 8'	Quartz and calcite.
At 8'	Veinlet one inch wide of pyrite, sphalerite and chalcopyrite along minor fault striking N62°E and dipping 85 degrees south.
8' to 12'	Altered and brecciated quartz diorite with criss-crossing quartz veinlets containing scattered grains of pyrite and an occasional grain of chalcopyrite and sphalerite. There are some included blocks of fresh quartz diorite.
At 12'	Fairly definite hanging-wall at a fault having considerable gouge but not as strong as the fault at the six foot point.

Wall Rock Alteration

The alteration of the quartz diorite is more intense where the faulting has been strongest and not necessarily where metallization has been greatest. The wall rock near the vein in the tunnel at 2510 feet where some massive sulphides are exposed shows a limited alteration. The rock is still hard and black and alteration consists of a partial replacement of the feldspars by calcite, epidote and chlorite. Along a fault in the lower cross-cut about 350 feet from the portal there is a forty foot wide bleached zone in which the quartz diorite has been altered with the production of a rock consisting primarily of quartz and sericite with considerable calcite and some chlorite, pyrite, and hematite. This bleached zone has no ore minerals.

Mineralogy

Among the gangue minerals quartz is the most common but considerable calcite is present. The inter-grown quartz and calcite occurring in the vein where it is cut by the Priestley cross-cut is interesting because of the peculiar graphic pattern produced by later filling in of calcite around well formed quartz crystals (cf Plate 65). The massive yellow stained quartz in the open-cut at 2700 feet elevation has been mentioned. It is also clearly the result of filling, with arsenopyrite and pyrite in the interstices between quartz grains. A few later fractures have been filled with fine grained quartz but brecciation is limited and at least eighty

PLATE 65

Photomicrograph of quartz and calcite stringer from the Lennox vein showing euhedral quartz crystals surrounded by calcite. (Plain light; x 12)

per cent of the quartz is aclastic.

Of the sulphides, arsenopyrite and pyrite are most abundant. Arsenopyrite is the chief mineral occurring in the quartz veins while pyrite is the chief mineral in the massive sulphide seams and in the altered wall rock. The arsenopyrite commonly forms exceptionally well formed diamond shaped crystals, with the brachydomes striated. A few of the crystals show twinning. The pyrite often forms small cubes in the altered wall rock, but in the seams of sulphides it is generally massive and often somewhat brecciated. Sphalerite is less abundant than pyrite but usually present in the sulphide seams. It forms in irregular cleavable masses an inch or less across intimately inter-grown with pyrite. A small amount of galena is often present in the sulphide seams as bright gray grains with good cubic cleavage. There is little evidence of replacement of one sulphide by another.

Devil's Canyon Prospect

Location and General Description

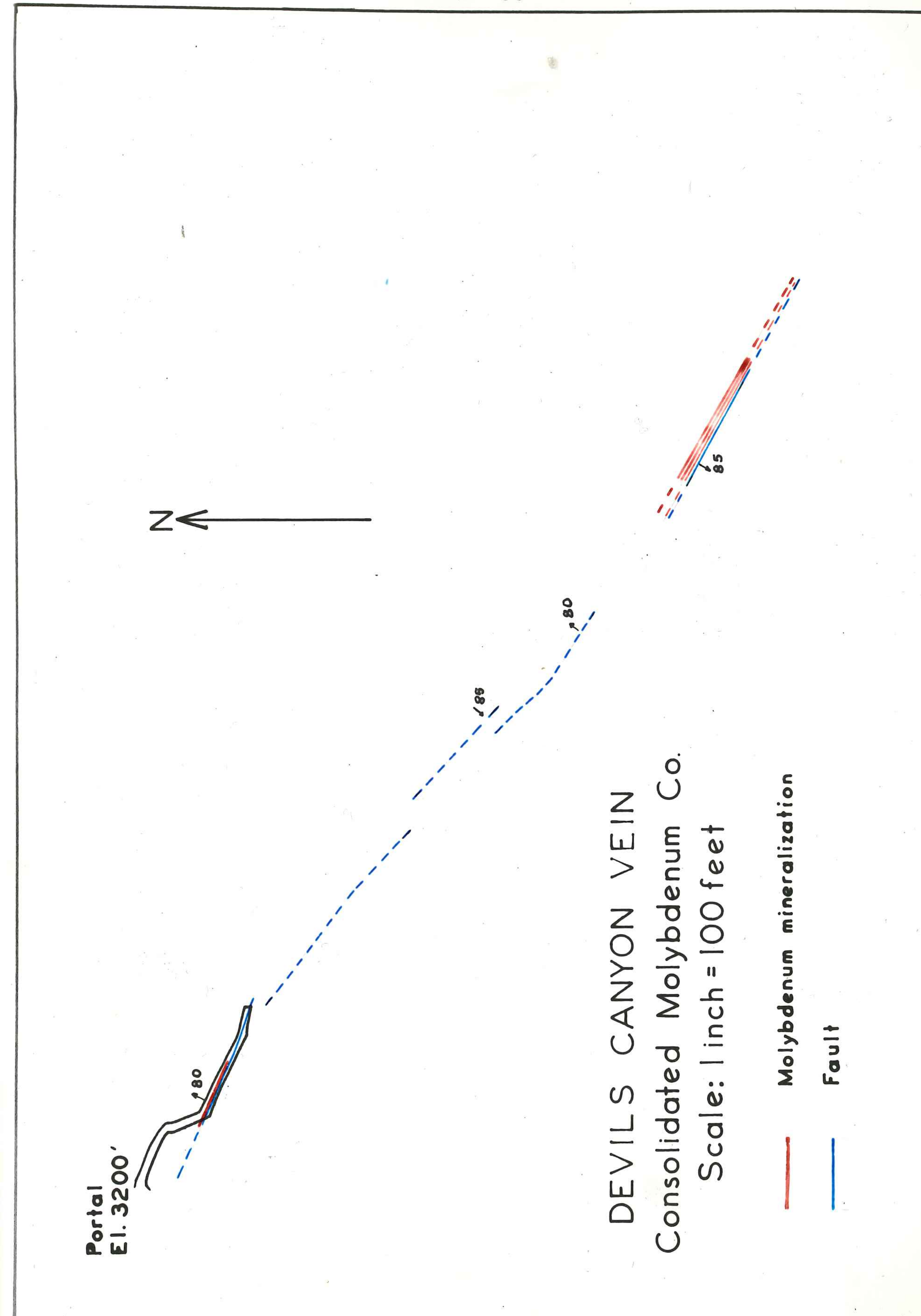
This property consists of a group of claims located about one-half mile northeast of the confluence of the Lennox River and Cougar Creek. The molybdenum deposit follows the course of a steep walled canyon called "Devil's Canyon," and for many years has been known as the Devil's Canyon mine. Development consists of one tunnel 160 feet in length that has its portal in the side of the canyon at 3200 feet elevation and then curves so that at seventy feet from the portal it intersects the vein under the center of the canyon and then drifts along it to the southeast for ninety feet.

The deposit consists of a fault zone in Snoqualmie granodiorite, striking approximately N57°W and dipping steeply to the northeast. Some molybdenum mineralization is exposed along the fault at two widely separated points as shown on the map (cf Plate 66).

Granodiorite in the vicinity of the property

The Devil's Canyon deposit falls within the area of the Snoqualmie granodiorite, and the rock in the vicinity of the lower tunnel is similar to the granodiorite occurring elsewhere, but somewhat richer in orthoclase. A thin section of a specimen from the northeast wall of the canyon by the portal of the tunnel shows the rock to consist of thirty per cent subhedral grains of oligoclase, twenty-five per cent orthoclase in large anhedral grains, twenty-five per cent quartz, ten per cent subhedral green hornblende, ten per cent of biotite in large plates, and minor amounts of tourmaline and magnetite. Some of the large grains of orthoclase and quartz enclose the earlier plagioclase. Farther up the canyon between the lower and upper mineralized zones the wall rock is light brown in color and contains numerous cavities lined with quartz druzes. A few cavities are lined with calcite in a radiating, sheaf-like structure. This light brown rock when examined under the microscope shows the effects of hydrothermal alteration on a normal granodiorite with replacement of the

PLATE 66


DEVILS CANYON VEIN
Consolidated Molybdenum Co.
Scale: 1 inch = 100 feet
Molybdenum mineralization
Fault
Portal
El. 3200'
N
80
85
86
80

oligoclase and orthoclase by sericite. The orthoclase is almost completely replaced and the plagioclase partly replaced. The original hornblende and biotite is largely altered to chlorite. This light colored rock does not occur as an alteration halo around the vein, but extends off to the northeast for a considerable distance, a similar rock outcropping about one-third mile distant on the trail from Devil's Canyon to Anderson Gap.

Just northeast of the canyon and about two hundred feet in elevation above the trail leading from the cabin to the tunnel portal this altered granodiorite outcrops in a high cliff. This granodiorite contains many veinlets of quartz and numerous cavities filled with quartz druzes, and some lighter quartz rich patches with no apparent continuity. Examination of a thin section of this rock shows it to consist of fifty per cent quartz, thirty per cent sericite, formed from alteration of feldspars, about ten per cent unaltered orthoclase and plagioclase, five per cent biotite and five per cent chlorite. It is probable that some of the quartz was formed as a product of the reaction whereby feldspar was altered to sericite. In some of these quartz druzes the individual quartz crystals are more than an inch across and some interest has been shown in this occurrence as a possible source of optical grade quartz. A talus slope, to the north of this outcrop, which reaches to the trail leading from the cabin to the tunnel is composed largely of this light colored rock, some blocks of which show large radiating bundles several inches across of black shiny tourmaline needles.

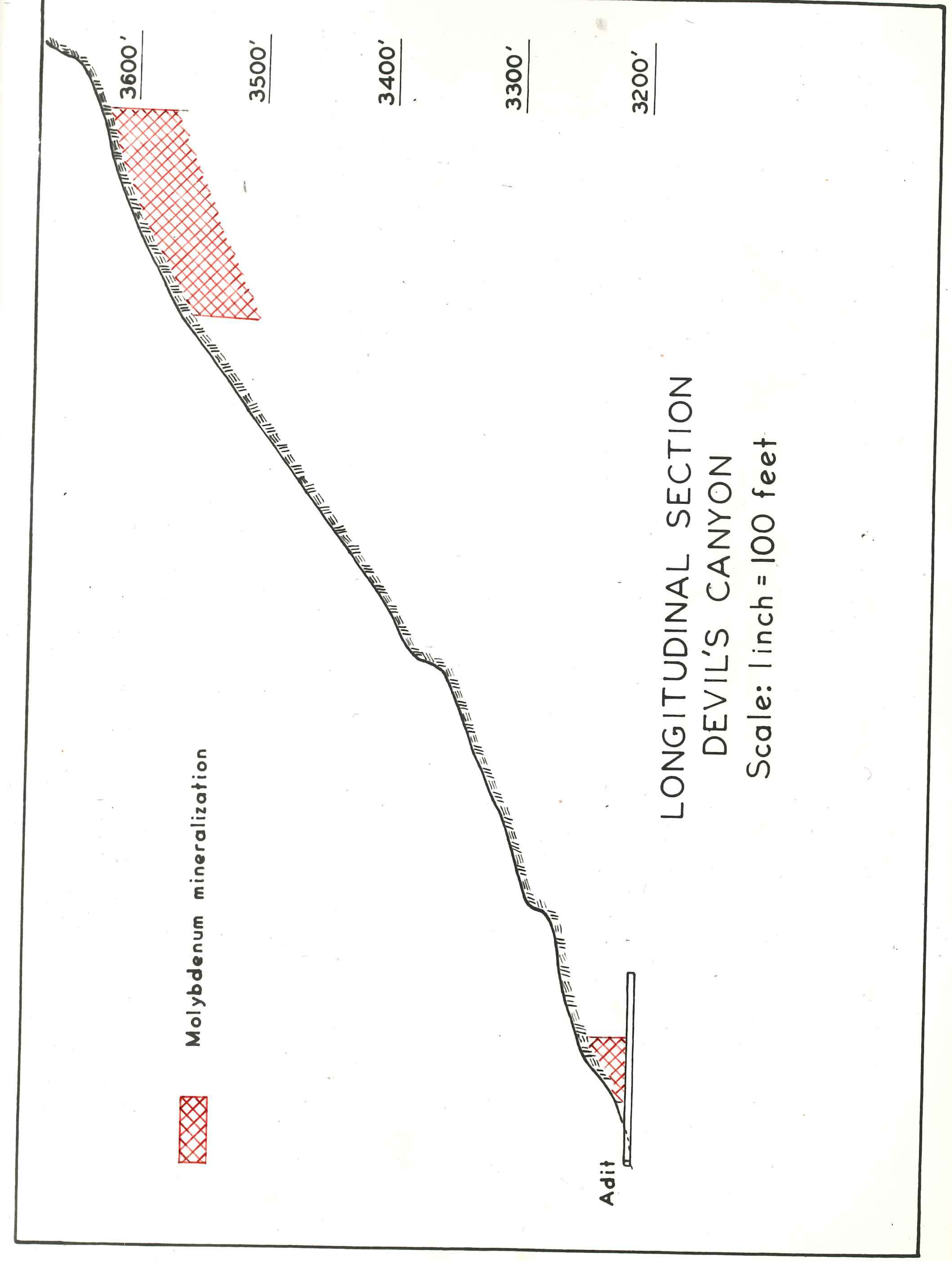
The association of tourmaline with metallization at several localities throughout the area, such as at the Quartz Creek and Jack Pot properties suggests that the occurrence of molybdenum can be genetically associated with this area of sericitized granodiorite with its relatively high tourmaline content.

Structure

The faulting in the canyon corresponds with the regional strike of the most important jointing in this part of the Snoqualmie granodiorite. The fault zone is more easily eroded than the surrounding rock due to brecciation and alteration which has occurred along it, so that it forms the course of a small stream. The action of running water in the spring and summer and freezing and thawing at the margins of the snow which lies in the canyon in winter has formed a canyon with a very steep and step-like profile (cf Plate 67), and in places nearly vertical walls. Ropes have been placed by the owners at two locations to aid in climbing the steep canyon.

The fault zone follows the floor of this canyon and is exposed in some places and covered by fallen rock in other places. Over part of its length the faulting is concentrated in a one-foot wide zone marked by gouge and brecciated wall rock. At a point about mid-way along the deposit another parallel fault to the northeast of the main fault appears and

PLATE 67


3600'
3500'
3400'
3300'
3200'
Molybdenum mineralization
Adit
LONGITUDINAL SECTION
DEVIL'S CANYON
Scale: 1 inch = 100 feet

causes a branching of the canyon at this point, with a fault in each branch. These faults dip toward each other and would undoubtedly come together a short distance below the surface.

As seen on the map (Plate 66), the mineralized portions of the fault zone have a strike of approximately N65°W while the fault zone in between these zones strikes throughout most of its length N57°W. It is possible this slight change of direction of the fault zone has resulted in the openings which have been filled with quartz.

Mineralization

The lower mineralized zone is much smaller than the upper zone. It is exposed where the tunnel intersects the fault zone after traversing through massive and fairly fresh granodiorite from the portal in the northeast wall of the canyon. Here the fault zone is dipping eighty degrees to the northeast and consists of a fault on the foot-wall or north-east side with five inches of gouge containing fragments of quartz with scattered molybdenite flakes, and also some black streaks of finely divided molybdenite. Next to the gouge is twenty-two inches of brecciated granodiorite followed by another fault on the hanging-wall side with a small amount of gouge. It is estimated that the five inches of gouge would average about three per cent molybdenum. At fifty feet east of where the tunnel first intersects the vein the gouge containing molybdenite is two inches wide. Near the face of the tunnel no molybdenum mineralization is present. A "Mineralight" reveals the presence of some tungsten in the form of scheelite-powellite along with the molybdenite in the gouge.

The upper mineralized zone is four hundred feet higher in elevation and about six hundred feet east of the lower zone. It is exposed in the floor of the canyon for a distance of approximately two hundred feet. Mid-way along this length the vein is vertical and strikes N65°W. Starting at the south wall of the canyon the vein shows eight inches of quartz containing flakes of molybdenite, then eight inches of brecciated and altered reddish colored granodiorite, three inches of quartz containing about ten per cent molybdenite, three inches of gouge, two inches of quartz with some molybdenite, and finally eight inches of gouge, with reddish colored and altered granodiorite on the north side of the vein. Along the vein to the northwest the quartz stringers spread out gradually and finally die out. To the southeast the walls of the vein gradually converge and the amount of quartz and molybdenite decreases. One hundred feet southeast of the section described above the vein has narrowed appreciably and the canyon floor rises vertically for a considerable height and the mineralization has not been followed on the surface beyond this point.

Molybdenite is the only conspicuous ore mineral. In the quartz stringers it appears as foliated grains, usually one-eighth to one inch in size (cf Plate 68). Occasionally the molybdenite occurs along fractures in even larger plates and there are reports of plates many inches long having been taken from the upper mineralized section.

PLATE 68

Photograph of quartz containing large flakes of molybdenite from upper mineralized zone of Devil's Canyon prospect.

The quartz is coarsely granular and appears to be largely the result of filling. In thin section the molybdenite can be seen to occur between the quartz grains and along fractures in the quartz. The vein has suffered from some recurrent fracturing and locally the molybdenite is strung out in elongated streaks of the pulverized mineral. Some scheelite-powellite occurs in the quartz with the molybdenite. It is nearly white in color and very hard to locate without an ultra violet light.

Langer and Rainbow Claims

Along the Lennox River above the Lennox mine the Snoqualmie granodiorite is in contact with tuffaceous sediments and argillites and graywackes of the Calligan formation. These sedimentary rocks are metamorphosed to fine grained hornfelses and coarser biotite quartz granulites, including some with red garnets. At some spots within these metamorphosed rocks are veins of sulphides. These sulphide veins have a strike similar to that of the other veins within the map area but the faulting associated with the veins in the granodiorite is not present in these deposits. Quartz is absent and the metallization is quite variable within short distances. There is no noticeable low temperature alteration of the wall rock, which, together with the association of the sulphides with garnet zones near the contact, is taken as evidence that the temperatures at the time of vein formation were high.

The Langer claims are located along the Lennox River about one and one-half miles above its confluence with the North Fork of the Snoqualmie River. A seam of sulphides outcrops in a low cliff of metamorphosed sediments just north of the Lennox River mine to market road. This seam is about four inches wide and consists chiefly of very dark brown sphalerite, but there is some chalcopyrite and pyrrhotite. The owners have built a camp and started a tunnel at the foot of the cliff to prospect this showing of sulphides. This four inch wide seam of sphalerite does not extend down to the tunnel level twenty feet below, but some scattered chalcopyrite occurs along with some garnet in the metamorphosed rocks in the portal of the tunnel. About twenty feet from the portal the face of the tunnel is now in Snoqualmie granodiorite. No faulting is present.

The Rainbow prospect lies down stream and across the Lennox River from the Langer tunnel. A seam of sulphides is exposed at 2460 feet elevation in a small canyon leading south from the river. The seam varies in width from one to six inches where exposed, and is not accompanied by visible faulting. The chief sulphide is pyrrhotite, with some chalcopyrite, and, according to one of the owners, Edwin Sauers, a spectrograph showed a trace of tin. The vein strikes N83°E which almost puts it in line with the sulphide seam on the Langer claims. The wall rocks are highly metamorphosed argillites and light colored tuffaceous sediments with a very irregular outcrop pattern.

Pieces of float of sulphides very similar to those observed on the Rainbow claim were observed in a canyon south of Sunday Lake. The pyrrhotite-chalcopyrite seams were found in pieces of dark colored fine grained hornfels. This canyon cuts across the contact between the granodiorite and the Calligan formation. Similar pyrrhotite-chalcopyrite seams, but contained in fine grained quartz diorites, occur in the bed of Quartz Creek a mile above the Taylor River.

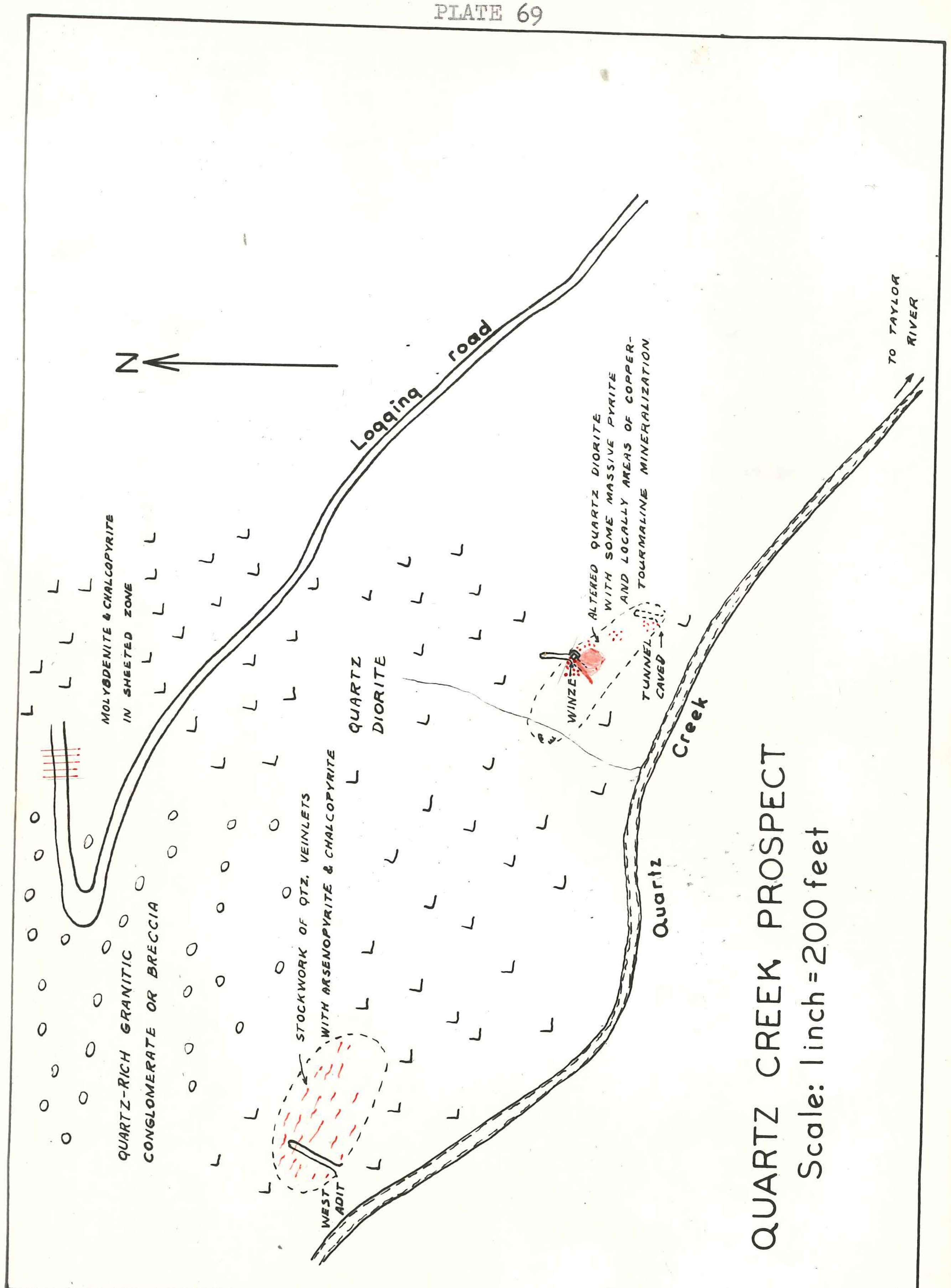
Quartz Creek Copper Deposits

General features

Several short adits are present along the north side of Quartz Creek below the Quartz Creek logging road about three-fourths mile from the Taylor River. The rocks in this vicinity are mostly quartz diorites of the Quartz Creek Complex. A quartz diorite of fairly uniformly medium grain size starts at the first switchback in the Quartz Creek Road and extends westward up Quartz Creek for at least a mile. Within a distance of 800 feet within this quartz diorite are several outcrops containing copper sulphides (cf Plate 69). The mineralization is peculiar in that the association of minerals is different at the different exposures.

The greatest amount of prospecting has been done on a body of iron pyrite with some chalcopyrite and bornite which outcrops in a low cliff just above Quartz Creek in Section 16,

PLATE 69



QUARTZ CREEK PROSPECT
Scale: 1 inch = 200 feet

Township 24 North, Range 10 East. A prospecting adit has been driven for a distance of fifty feet into this cliff. Just inside the portal of this adit a winze has been sunk to a depth of about forty feet, but the winze is filled with water. The material on the dump which probably came from this winze is estimated to carry two and one-half per cent copper, principally as chalcopyrite.

About 800 feet west from the above outcrop a stockwork of criss-crossing quartz veinlets and lenses in fine to medium grained quartz diorite outcrops at several places over an area of roughly 100 by 200 feet. The area is in heavy timber and outcrops are few. About 100 feet from the bank of Quartz Creek an eighty foot adit bearing N37°E has been driven to cross-cut this stockwork at a depth of about forty feet. The chief sulphides are arsenopyrite and chalcopyrite.

The third outcrop of interest occurs at the first switch-back in the Quartz Creek logging road. In blasting the road cut there was exposed some fine grained quartz diorite with a zone about forty feet wide through which closely spaced fractures striking nearly north-south are lined with quartz, pyrite, chalcopyrite, arsenopyrite and some molybdenite and scheelite.

Mineralogy and structure at the winze adit

In an area at least 200 feet long and at least forty feet wide around the winze adit the quartz diorite has been irregularly altered to a light colored aggregate of quartz and sericite with some scattered needles of black tourmaline. There are places within this altered zone where the quartz diorite is quite fresh so that it appears that the alteration is controlled by the presence of brecciation and faulting. On the east wall of an opencut leading to the portal of this adit there is exposed an irregular shaped outcrop of massive pyrite about thirty feet in diameter. This pyrite has formed by replacement of the wall rock and relics of quartz and sericite and partially altered quartz diorite are contained in it. The only megascopically visible evidence of copper in this massive pyrite is a thin coating of a blue mineral, probably covellite, on some fractures in the pyrite.

On the west wall of the opencut is a seam about one foot wide in the massive pyrite which contains considerable copper, partly as chalcopyrite and partly as bornite and covellite. The bornite and covellite appear to be secondary. This seam and also some pieces of ore on the dump which apparently came from the winze contain some white to light grayish green colored crystals up to two inches across. These crystals are completely altered to sericite and a lesser amount of chlorite. A continuous x-ray spectrum on one of these crystals showed no trace of any constituents other than sericite and chlorite. The crystals, which are exceptionally well formed, are elongated and usually asterated due to penetration twins of two triangular shaped prisms such as tourmaline. The crystals usually pull free from the sulphides rather easily and reveal the impression of their crystal outline on the surrounding pyrite and chalcopyrite. The crystals are commonly partly replaced by chalcopyrite. This seam of copper sulphides fades out near the portal of the adit and appears to be striking almost perpendicular to the general trend of the brecciated and altered zone.

On the west wall of the adit opposite the winze are ten feet of quartz and sericite containing disseminated pyrite and black needles of tourmaline, and also about two and one-half per cent copper in the form of chalcopyrite partly altered to bornite. The form of this mineralization is very irregular and shows no inclination to follow any particular direction. The adit continues beyond the area of copper mineralization on which the winze has been sunk, but beyond the winze it shows only a stockwork of small quartz veinlets in the quartz diorite with traces of chalcopyrite but with little alteration and no tourmaline. Assuming that the asterated six pointed prisms were tourmaline it appears that the strongest copper mineralization is at places where tourmaline is present. This association of copper with tourmaline has been described from numerous places in North and South America. They represent deposits formed at fairly high temperatures although in this case the fact that part of the tourmaline is completely altered to sericite and chlorite indicates temperatures dropped during the later stages of the mineralization.

Mineralogy at the west adit

At the adit 800 feet west of the winze adit the alteration of the quartz diorite is much less intense. The quartz veinlets of the stockwork cut fresh appearing quartz diorite and no tourmaline was observed. A small amount of chalcopyrite is disseminated through most of the quartz diorite near the adit. The most conspicuous sulphide is arsenopyrite which occurs in the quartz veinlets, sometimes in fairly coarse grains up to one inch in size. Associated with the arsenopyrite in the veinlets is some chalcopyrite, and polished sections of the arsenopyrite show the chalcopyrite to be later and to be replacing the arsenopyrite along fractures. A small amount of molybdenite was also observed associated with chalcopyrite. Although the quartz veinlets are slightly more numerous and they contain more sulphides in the twenty feet near the face of the adit there is no local concentration of chalcopyrite such as observed in the winze adit. Also the low temperature alteration and the development of secondary copper sulphides are not apparent here.

Mineralogy at the road cut outcrop

The mineralized outcrop on the logging road is contained in a fine grained dark gray rock of quartz dioritic composition. This rock over a width of about forty feet has been fractured so that it has developed a sort of sheeting striking about north-south. If a piece of this fractured quartz diorite is hit with a hammer it tends to break apart along the fracture planes and the surfaces are lined with small grains of chalcopyrite, molybdenite, and arsenopyrite. Many of the fractures have small quartz veinlets less than an inch wide and those quartz veinlets sometimes contain larger flakes of molybdenite up to one-half inch across. Some scheelite was also observed.

A thin section of the quartz diorite from near one of the quartz veinlets shows the quartz diorite to have been fractured and recrystallized. Much of the feldspar has been altered to sericite, with the release of some quartz. Chlorite is scattered through the more altered parts of the rock, while the less altered parts show considerable reddish brown biotite.

Immediately west of this outcrop along the road is an outcrop of the granitic conglomerate described in connection with the Quartz Creek Complex.

Structural features

This is not a simple vein or fault zone but appears to be an irregular shaped replacement deposit in a brecciated zone. The deposit is in an area of considerable timber and overburden and the true outline of the deposit is in doubt. However, the strikes of some minor fractures in the winze adit and the adit to the west are along a general east-west direction. The outcrop at the bend in the Quartz Creek logging road shows the small mineralized fractures striking about north-south. Thus this latter outcrop and the east-west striking zone including the two other outcrops form a triangle around the nose of the outcrop of granitic conglomerate. It appears that the brecciation in the granitic conglomerate (cf above) and the fracturing in the quartz diorite in which most of the mineralization occurs took place at the same time and the concentration of copper sulphides in the quartz diorite is mainly due to the ability of this fairly uniformly textured quartz diorite to maintain open fractures through which the ore solutions could move.

As the copper mineralization as exposed in the winze adit appears to be localized in part by minor faults and fractures which cut across the general trend of the outcrop pattern it is likely the ore shoots will not be tabular in shape but will tend toward an irregular pipe- or lens-shaped body. It is also probable the copper mineralization will stay rather close to the semi-circular area around the granitic conglomerate where the outcrops described above occur.

Geology as an Aid to Prospecting

Hard, brittle rocks are more common as wall rocks because they could support more open fractures. This accounts for the fact that almost all of the veins are in such rocks as granodiorite and quartz diorite. Only small amounts of metallization are found in the hornfelses and these are higher temperature veins with pyrrhotite. There is little evidence in them of any original fracturing and they lack the regularity of the veins in the more brittle rocks.

The veins in the granodiorite are closely related to the strongest joint system and in some instances the veins appear to be mineralized joints. Since the intersection of two faults, or the intersection of a fault and a joint, or small tensional fractures between two shears were more apt to be open than simple fractures they provided better access to the ore bearing solutions and thus we find such places as favorable spots for the localization of ore shoots. In some cases a slight change in direction of a fault appears to have resulted in an open space which was filled by later vein material as in the case of the Devil's Canyon prospect. In the cases where the ore shoots are localized by the intersection of fractures the pitch of the ore shoot will be determined by the dip and strike of the two fault planes and the resulting direction of their intersection, which usually will not be vertical.

Alteration of the wall rock has in many cases been earlier than the metalization and therefore zones of sericitization and pyritization, while often showy looking, do not necessarily surround ore shoots. Some wide zones of alteration are barren while some seams of ore have relatively slightly altered walls.

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VITA

Horace Lloyd Bethel, son of Joseph and Ruth Bethel, was born October 29, 1916 at Tacoma, Washington. He attended grammar, intermediate, and high schools at Tacoma, Washington and graduated from Lincoln High School in 1934. He matriculated at the University of Washington and graduated in 1939 with a bachelor of science degree in mining engineering.

From 1939 to 1941 he was a mining engineer and geologist for the International Engineering Corporation in the Philippine Islands. During the year 1942 he was a mining engineer with the United States Army Engineers in Seattle, Washington. In 1942 he enlisted in the Army and was sent to a meteorological training unit at the California Institute of Technology. Following one year of training, during which he fulfilled the necessary requirements for a master of science degree in meteorology, he was commissioned a second lieutenant and served as an instructor in meteorology during 1944. During 1945 and part of 1946 he served as an engineer officer with the 1908th Engineer Aviation Battalion in the Pacific Theatre. He was a consulting mining engineer and geologist from 1946 to 1949. From 1949 to 1951 he was a teaching fellow and graduate student at the University of Washington.

He is a member of Tau Beta Pi and an associate member of Sigma Xi.

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PLATE 70

GEOLOGIC MAP of the SOUTHEASTERN PART OF THE SKYKOMISH QUADRANGLE

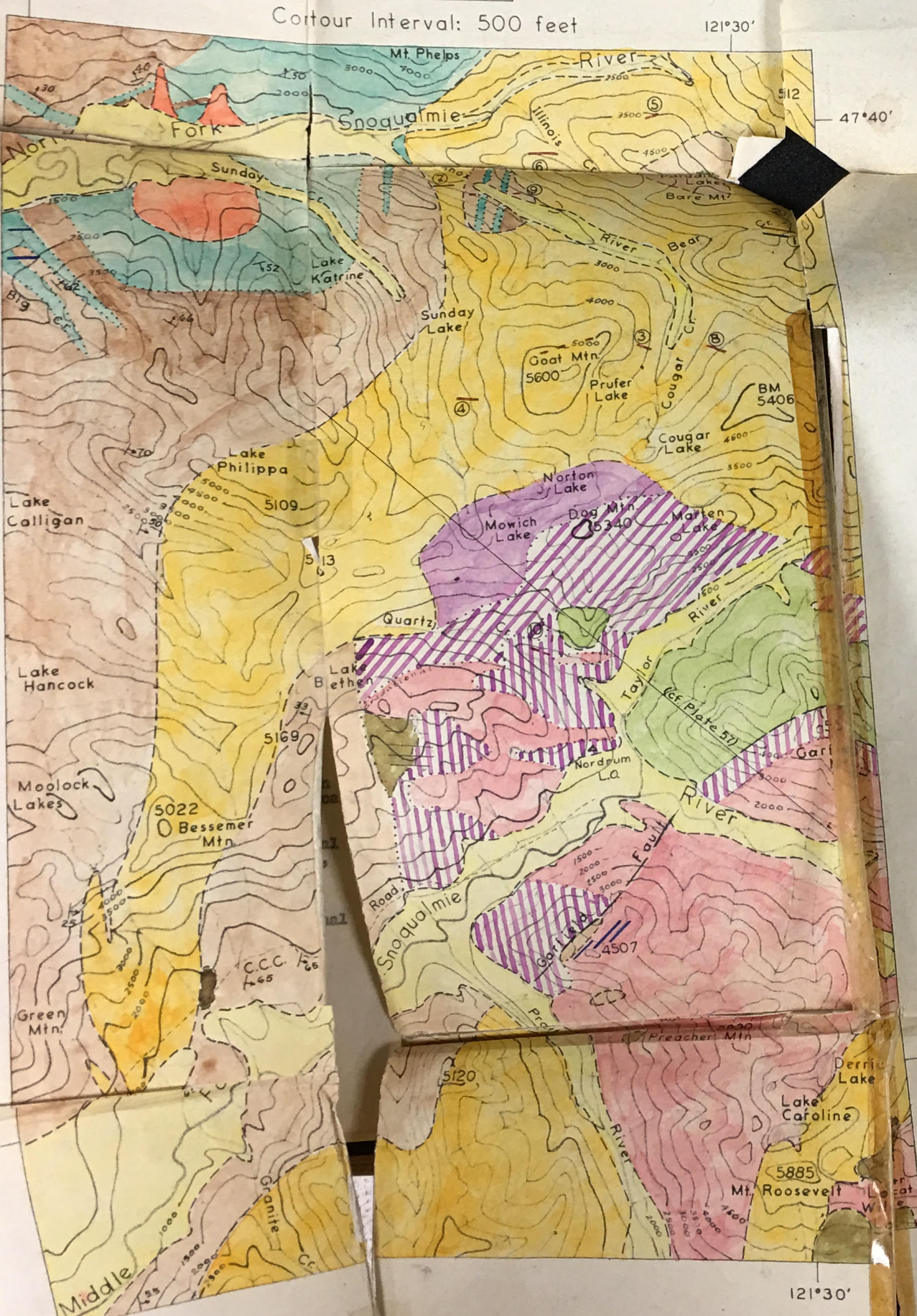
King County, Washington

Scale

1/2 0 1 mile

Contour Interval: 500 feet

121°40′ 121°30′ 47°40′



47°30′ 121°40′ 121°30′

EXPLANATION

SEDIMENTARY ROCKS

ALLUVIUM and GLACIAL DEPOSITS (Sands, Gravels, and Glacial Clays) — Quaternary

CALLIGAN FORMATION (Graywackes Argillites, Tuffaceous Sediments, with interbedded Tuffs in large part mapped separately as Mt. Phelps ...) — Early Tertiary to Cretaceous

VOLCANIC ROCKS

MT. GARFIELD VOLCANICS (Andesite breccias, Tuffs, and massive Andesites)

MT. PHELPS VOLCANICS (Andesitic to rhyolitic tuffs and breccias with some massive andesites.) Some tuffs are interbedded with Calligan formation.) — Early Tertiary to Cretaceous

METAMORPHIC ROCKS

LAKE WILDCAT METAMORPHICS, ETC. (Amphibolites, mylonitic schists, and greenstones, possibly metamorphosed Calligan formation.)

MINOR INTRUSIVES

DIKES (Andesite and more silicic.)

ROCKS OF QUARTZ DIORITIC TO GRANITIC COMPOSITION

SNOQUALMIE GRANODIORITE (Light gray rock composed of andesine, orthoclase, quartz, hornblende and biotite.)

PREACHER GRANITE (Nearly white rock composed of orthoclase, oligoclase, and biotite; partly granophyric.)

SUNDAY GRANITE (Light-colored rock composed of orthoclase, quartz, oligoclase and biotite.)

QUARTZ CREEK QUARTZ DIORITE COMPLEX

(Area of gree... ...nalite.)

(Area of heterogeneous ...ranitic rocks and minor quartz ...orite.)

(Area of fine grained qu...rtz diorite with minor gran...e.)

Contact observed or i...rred

Contact conjectural or d...ramatic

Fault