

GEOLOGY OF THE NORTHEASTERN QUARTER OF CHIWAUKUM
QUADRANGLE, WASHINGTON

by

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Abstract of

A thesis submitted in partial fulfillment for the degree of

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ABSTRACT

Chiwaukum quadrangle is near the geographical center of the State of Washington. It is bounded by meridians 120 degrees 30 minutes and 121 degrees west longitude and by parallels 47 degrees 30 minutes and 48 degrees north latitude.

Presumably in late Jurassic time (Nevadian disturbance), a thick succession of fine and medium grained clastic sediments along with basic igneous rocks and subordinate quantities of limestone were intensely deformed, regionally metamorphosed and metasomatically migmatized and granitized (sodium enrichment followed by potassium enrichment). The non-granitized rocks consist of biotite-muscovite-quartz-schist, staurolite-biotite-quartz-schist, amphibolite-schist, and marble. The granitized rocks consist of biotite-gneiss, quartz-diorite-gneiss, granodiorite-gneiss, and diorite.

Before deposition of the Paleocene arkoses of the Swauk formation, numerous dikes (ranging from spessartites to granophyres) were emplaced in the rocks of the Metamorphic Complex. They appear to be derived from a common parent magma that was

injected at various stages in the process of differentiation.

By late Cretaceous time, Central Washington was part of a widespread coastal lowland. It may have extended southward from British Columbia into Oregon and westward from Idaho to and beyond the present position of the coast.

During Paleocene and possibly beginning in late Cretaceous time, the coastal lowland subsided differentially and received a thick succession of continental sediments, the Swauk formation. In Chiwaukum quadrangle, the total downwarping was sufficient to permit the accumulation of over 12,000 feet of arkosic sediments.

The sediments of the Swauk formation were transported and deposited by large westward flowing streams, building aggradational plains of coalescent sheets and lenses of alluvial detritus. They may have been deposited over a widespread area including large portions of Central and Western Washington. It is possible that they were continuous with deposits in Western Washington which may represent, in part, the deltaic deposits of the streams.

Minor folding took place during Swauk sedimentation in the area of Wenatchee quadrangle (Chappell, 1936), but, for the most part, folding was after deposition.

After the Swauk formation was deposited, the rocks were folded, faulted, and differentially uplifted into structures bearing north 30 degrees west. Faulting and differential

uplift produced a large graben and placed approximately twelve thousand feet of Swauk strata in fault contact with the rocks of the Metamorphic Complex.

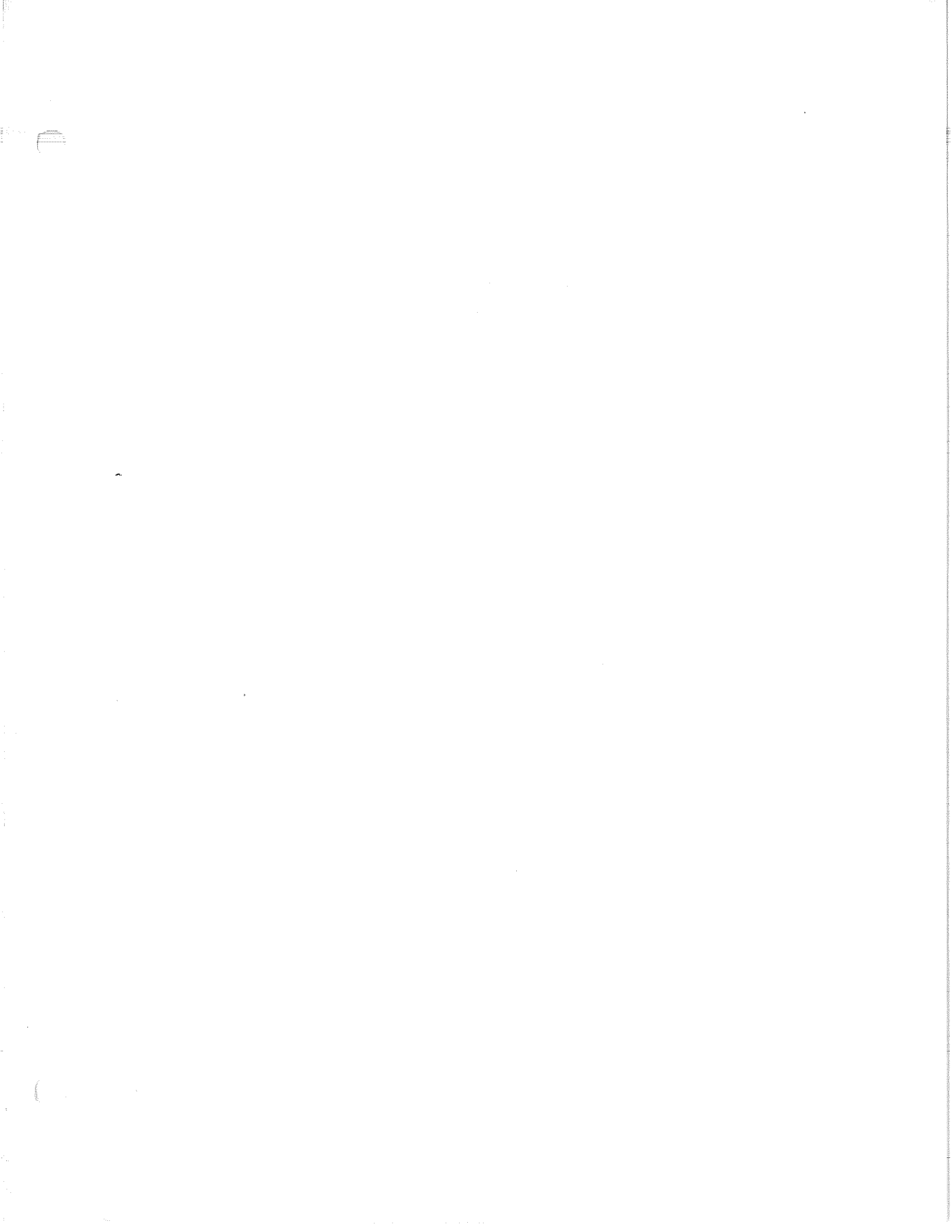
The major fault that defines the Swauk filled graben on the east is also the major structural feature of the Entiat Mountains. The Entiat Mountains are not anticlinal mountains as previously described, but they are controlled by faulting.

Contemporaneous with or after faulting, magma was emplaced along the fault surfaces to form diabase dikes and an asymmetrical laccolith of hornblende-dacite-prophyry. South of Natapoc Mountain, magma was emplaced along the Swauk strata to form a diabase sill.

Before the broad regional uplift that gave rise to the Twisp stage of erosion and the Cascade Mountains, erosion reduced the surface to a broad valley stage, the Entiat stage, over a widespread area. The relic flow of hypersthene-ande-site-porphyry on Sugarloaf Peak and the Summit conglomerate on Natapoc Mountain appear to rest upon this surface.

In late Tertiary time, further deformation took place along northeast-southeast structural trends. It is illustrated by several folds in the flows of the Yakima basalt southeast of the area under consideration. An anticline, the Badger Mountain uplift, was formed southeast of the Entiat Mountains, and another, the Wenatchee Mountain uplift, was produced southeast of Mt. Stuart, the highest erosional remanent in the





Cascade Mountains. These two anticlines are separated by a broad downwarp southeast of the Swauk filled graben in Chiwaukum quadrangle.

Contemporaneous with or after the folding of the Yakima basalt, the area now occupied by the Cascade Mountains was warped into a major, broad upwarp with a north-south trending axis. This structure was superposed on the earlier northwest-southeast structural trends.

Erosion was greatly accelerated, the Twisp cycle, by the uplift. Rejuvenated streams cut deep, narrow inner canyons in the broad valleys of the Entiat surface. Sediments of the Swauk formation were flushed out of the graben. As a result, a fault-line scarp was produced along the western border of the Entiat Mountains.

During late (?) Pleistocene time, the canyons were occupied by glaciers. As a result, lakes and a complex marginal drainage were developed.

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INTRODUCTION

Geographical Position of Area

Chiwaukum quadrangle is near the geographical center of the State of Washington. It is bounded by meridians 120 degrees 30 minutes and 121 degrees west longitude and by parallels 47 degrees 30 minutes and 48 degrees north latitude (Plate No. 1). Nearly all the quadrangle is in Chelan county, but an area of less than one square mile is in Kittitas county.

The area under consideration occupies approximately the northeastern quarter of Chiwaukum quadrangle (Plate No. 1). It is of irregular outline and covers an area of approximately 275 square miles.

The area may be reached by railroad or highway. The Great Northern Railroad crosses the southwestern part of the

area with a station at the town of Winton. The area is also served by State Highways 15 and 15C. By highway, the area is 125 miles east of the city of Seattle and 14 miles north of the town of Leavenworth.

Purpose of Investigation

This investigation was undertaken to fulfill, in part, the requirements for the degree of Doctor of Philosophy at the University of Washington. The choice of the area of investigation was largely made because of the variety of geologic problems of local and regional importance it had to offer.

Method of Investigation

Field work was undertaken during the summers of 1947, 1948 and 1949. A total of approximately five months was spent in the field.

Field mapping was done by the compass and clinometer method. Photostatic copies of the topographic sheet of Chiwaukum quadrangle (U.S. Geological Survey, 1904) were used for a base map. The topographic sheet (Plate No. 2), which has a scale of one-half inch equals one mile and a contour interval of one hundred feet, was enlarged to a scale of one inch equals one mile.

Specimens of rock were collected from approximately 250 localities. Thin sections were made from the specimens of metamorphic and igneous rocks. Both thin sections and mechanical analysis were made from the specimens of sedimentary rocks.

Acknowledgments

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The author is indebted to those workers previously engaged in geologic studies in Central Washington. Their work is acknowledged throughout the text, and the areas previously mapped by them are shown in Plate No. 1.

GEOGRAPHY

Topography

Chiwaukum quadrangle is on the eastern slope of the Cascade Mountains. The western boundary of the quadrangle is but a few miles east of the main divide between the Puget Sound and Columbia River drainage basins.

The topography of Chiwaukum quadrangle is, for the most part, extremely bold and rugged (Plate No. 2). High ridges and peaks occupy the western half and the northeastern part of the quadrangle. An area of more moderate relief extends northwestward from the southeastern corner of the quadrangle. This area is between the Entiat Mountains to the northeast, Icicle Ridge and Tumwater Mountain to the southwest, Nason Ridge, Dirty Face Peak, and McCall Mountain to the west, and Basalt Peak to the north.

The relief in the area is great. The high ridges and peaks have elevations ranging between 5,500 and 8,600 feet. Elevations along the Wenatchee River and its main tributaries vary between 900 and 2,600 feet.

Drainage

Drainage of the area within Chiwaukum quadrangle is almost entirely through the Wenatchee River and its tributaries (Plate No. 2). An area in the northeastern part of the quadrangle is drained by the Entiat River and its tributaries. Both of these rivers flow into the Columbia River.

There are many lakes within the area, but for the most part they are small. The largest and most important one is Wenatchee Lake. It is fed by two rivers, White River and Little Wenatchee River, and is drained by the Wenatchee River.

Climate

The climate of Chiwaukum quadrangle varies greatly. The area around the town of Plain and to the southeast shares to some extent the semi-arid climate of eastern Washington. In the more highly elevated portions of the area, the climate is in common with that of the Cascade Mountains.

The precipitation¹ at Plain (elevation 1,800 feet) averages about 20 inches a year; at Chiwawa River station (elevation 2,872 feet), the average is approximately 53 inches; at

1 Climatological data were obtained from United States weather reports for weather stations at Stevens Pass, Plain and on the Chiwawa River twenty miles northwest of Plain (Plate No. 1). U. S. Department of Agriculture, Weather Bureau, Climatological Data, Washington Section, Seattle, Washington, 1938-1948.

Stevens Pass (elevation 4,061 feet), the average approaches 60 inches. The precipitation at Chiwawa River station and Stevens Pass is nearly the same and approximately three times greater than at Plain. Throughout the area, precipitation is greatest during the winter months, with the major part of the precipitation being in the form of snow.

The highest temperatures are in the month of July; the lowest temperatures are in the months of January and February. At Plain the yearly temperatures range from -22 to 104°F, and at Stevens Pass they range from -11 to 95°F. No records of temperature are available for the Chiwawa River station.

Vegetation

The greater part of the area is covered with timber and a luxuriant growth of underbrush. Ponderosa pine, lodgepole pine, douglas fir, white fir, western hemlock and alpine pine are common in the area drained by the Entiat River, while douglas fir, white fir, western hemlock, western red cedar, sitka spruce, ponderosa pine, and lodgepole pine prevail in the areas drained by the Wenatchee and Chiwawa Rivers. Ponderosa and lodgepole pine prefer dry sites, but the others are more abundant on north slopes or moist sites.

Rock Exposures

In the northeastern quarter of the quadrangle, the area under consideration, the number and area of rock exposures are relatively small. The combined area of all rock exposures is less than 10 per cent of the total area. Exposures are more numerous to the southeast where timber and brush is less abundant, and to the north and west where the peaks and ridges rise above the timber line.

Industries

The principal industries are lumbering, tourist and agriculture. All other industries depend upon these.

Much of the area is covered with merchantable timber, but logging is confined to a few scattered districts. A small lumber mill on the southern shore of Wenatchee Lake is the only mill within the mapped area. Most of the timber is trucked to mills southeast of the city of Leavenworth.

A number of tourist cabins and small summer homes are along Wenatchee Lake, Nason Creek, and Fish Lake. Hundreds of sportsmen visit this area each summer for fishing and in the fall for hunting.

A few scattered farms are along the valley flats near and southeast of Plain. Grain and forage crops constitute the principal products with orchard products being subordinate. Nearly all of the farms are irrigated.

PETROLOGY AND STRATIGRAPHY

General Statement

On the basis of relative age, petrology, and occurrence the rocks in the area under consideration may be divided into eight main units of diverse types. They are, from oldest to youngest, the (1) Swakane and (2) Chelan facies of the Metamorphic Complex, (3) pre-Swauk intrusives, (4) Swauk formation, (5) post-Swauk intrusives, (6) hypersthene-andesite-porphry, (7) Summit conglomerate, and (8) superficial deposits. The occurrence, distribution, descriptive petrology, petrogenesis, age and correlation of each unit will be treated in the following pages in the above order.

Metamorphic Complex

The Metamorphic Complex is composed of a diverse assemblage of rock types. For the most part they are transitional with one another, which, along with overburden and vegetation, makes accurate mapping of smaller units impossible and of large units difficult. Most of the rock types have a distinct foliation, and it is of importance to note that their foliation has a common attitude.

The Metamorphic Complex has been divided into two facies and mapped as such. The "granitic" rocks are referred

to as the Chelan facies and the others as Swakane facies. The rock types of the Chelan facies correspond to those of the Chelan batholith of Waters (1932). The Swakane facies includes the Swakane gneiss of Waters (1932) and the Chiwaukum schist of Page (1939).

Swakane Facies

The rocks of the Swakane facies have a large areal distribution. They extend southeastward from Maverick Peak to the Columbia River and, intermittently with "granitic" masses, from Rock Creek southward to Tumwater Mountain. Their western boundary has not been determined, but the author has traced these rocks west of the mapped area for several miles along Nason Creek, Little Wenatchee and White Rivers. Three inliers of rocks of the Swakane facies are in a northwest-southeast-trending belt six miles east of the city of Leavenworth (Page, 1939).

The rocks of the Swakane facies vary greatly in their petrologic character. Named in the order of their decreasing abundance, they consist of biotite-gneiss, biotite-muscovite-quartz-schist, amphibolite-schist, staurolite-biotite-quartz-schist, pegmatite and associated milky-quartz veins, talc-carbonate-rock, and marble.

Biotite-Muscovite-Quartz-Schist. Biotite-muscovite-quartz-schist is a common rock type. It is present southeast of Maverick Peak, but sparse outcrops (approximately 3 per

cent) makes its distribution somewhat in doubt. It is also present on Nason Ridge where it passes westward and southward into staurolite-biotite-quartz-schist.

Megascopically, the biotite-muscovite-quartz-schist is a finely to moderately foliated rock with variable quantities of quartz, biotite and muscovite. Quartz is usually the dominant mineral, but it may be subordinate to mica. Small crystals of garnet may or may not be present. The rock has a dirty-gray color on fresh surfaces and a reddish-brown or rusty color¹ on weathered surfaces. Surfaces parallel to the foliation usually have a splendid luster.

When examined under the microscope, thin sections of the biotite-muscovite-quartz-schist reveals a fine-grained schistose aggregate of biotite, muscovite and quartz with minor quantities of iron ore, garnet, apatite, plagioclase and zircon. Biotite is present as aligned plates with X yellow and Y and Z reddish-brown. It may have small inclusions of zircon with pleochroic haloes. The muscovite is colorless and non-pleochroic with a 2V of approximately 15 degrees. Both aligned and cross plates of muscovite are present, the latter showing post-kinematic crystallization (Fig. 1). They are usually associated with trends of magnetite which are parallel to the foliation. Quartz is usually the dominant mineral but it may

1 The rusty color is produced by oxidation of the iron ore and biotite.

PLATE NO. 3

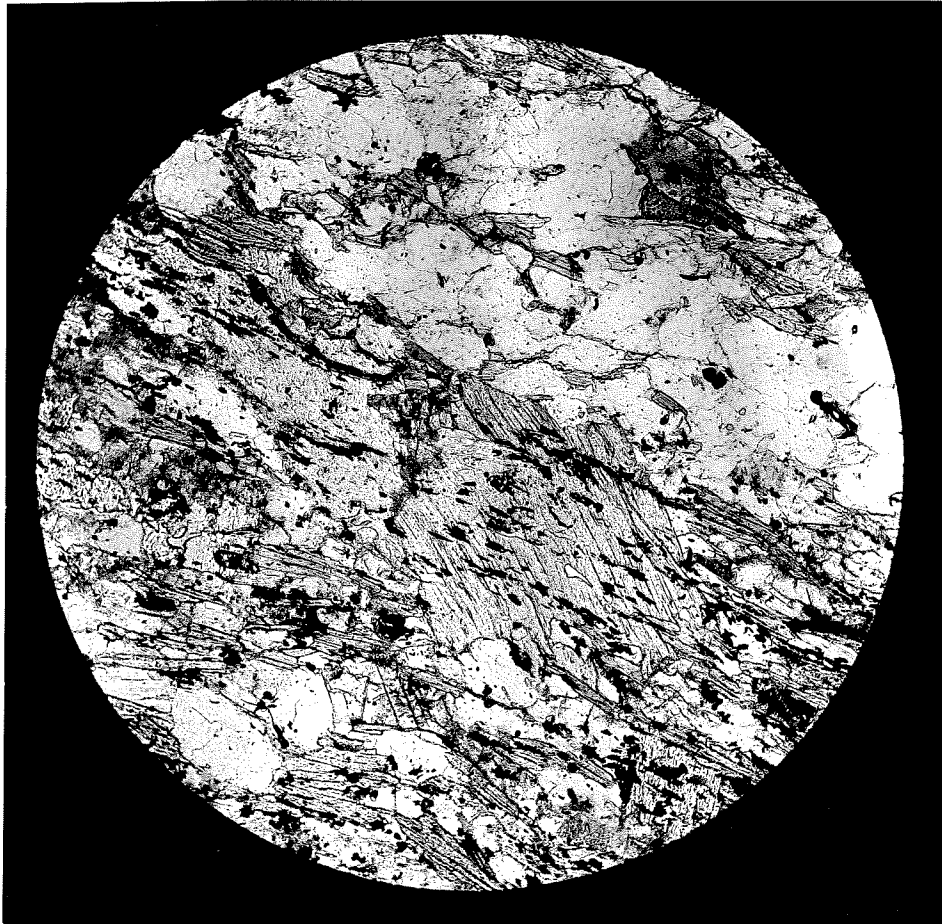


Fig. 1 - Photomicrograph of biotite-muscovite-quartz-schist showing cross plates of muscovite with trends of magnetite parallel to the foliation. The mica is dominantly biotite. (Plain light; X54)

be subordinate to mica. It is of anhedral habit with moderately interlocking to sutured contacts. Anhedral crystals of garnet with a maximum diameter of three millimeters are common but usually in small number. They have inclusions of quartz, biotite and muscovite. The iron ore is magnetite which may be altered, in part, to limonite. It is intimately associated with the mica. Small subhedral to euhedral, prismatic crystals of apatite have a random distribution throughout the rock, but they are only a minor constituent. Calci-oligoclase (An_{26}) of anhedral habit may be present but only in minor quantities.

Staurolite-Biotite-Quartz-Schist. The staurolite-biotite-quartz-schist occurs along Chiwaukum Creek, the type locality for the Chiwaukum schist (Page, 1939), which is one mile north of the Mt. Stuart granodiorite massif. The areal distribution of this rock type is not known, but Page (1939) traced the Chiwaukum schist six miles west of the mapped area along Chiwaukum Creek to the headwaters of Cougar (Panther) Creek, and similar rocks were observed by the author on Nason Ridge in the vicinity of Merritt Lake where they pass eastward into biotite-muscovite-quartz-schist. It has not been found elsewhere in the area under consideration.

On fresh surfaces, the rock is a dark gray to grayish-black, fine-grained schist with small crystals of biotite, staurolite, quartz, and magnetite visible with the aid of the hand lens. Light gray, fine-grained, quartose layers are com-

monly present to give the rock a banded appearance. On weathered surfaces, the rock has a reddish-brown color.¹

When viewed under the microscope, thin sections (Fig. 2) of the rock reveal schistose structures, crystalloblastic textures, and a mineral assemblage of staurolite, biotite, quartz and magnetite with minor and variable quantities of muscovite, graphite, garnet, chlorite, zircon and feldspar. The staurolite occurs as euhedral to anhedral porphyroblasts with a maximum diameter of three millimeters and a pleochroism of X colorless, Y pale yellow and Z golden-yellow. It commonly has numerous inclusions of quartz which gives it a sieve structure. The staurolite shows both synkinematic and post-kinematic crystallization. The former is illustrated by S-shaped lines of inclusions of magnetite and graphite that merge into similar lines of inclusions in the surrounding matrix. Those prismatic crystals of staurolite that are transverse to the foliation with undisturbed trends of inclusions bear witness that crystallization was also post-kinematic. Flakes of biotite with X yellow and Y and Z reddish-brown are a common constituent. The biotite has random orientations and pronounced helizitic structures which show that crystallization was post-kinematic. Minute inclusions of zircon with pleochroic haloes may sometimes be observed. The biotite is usually fresh but it may be

1 The reddish-brown color is produced by oxidation of the iron ore and biotite.

PLATE NO. 4

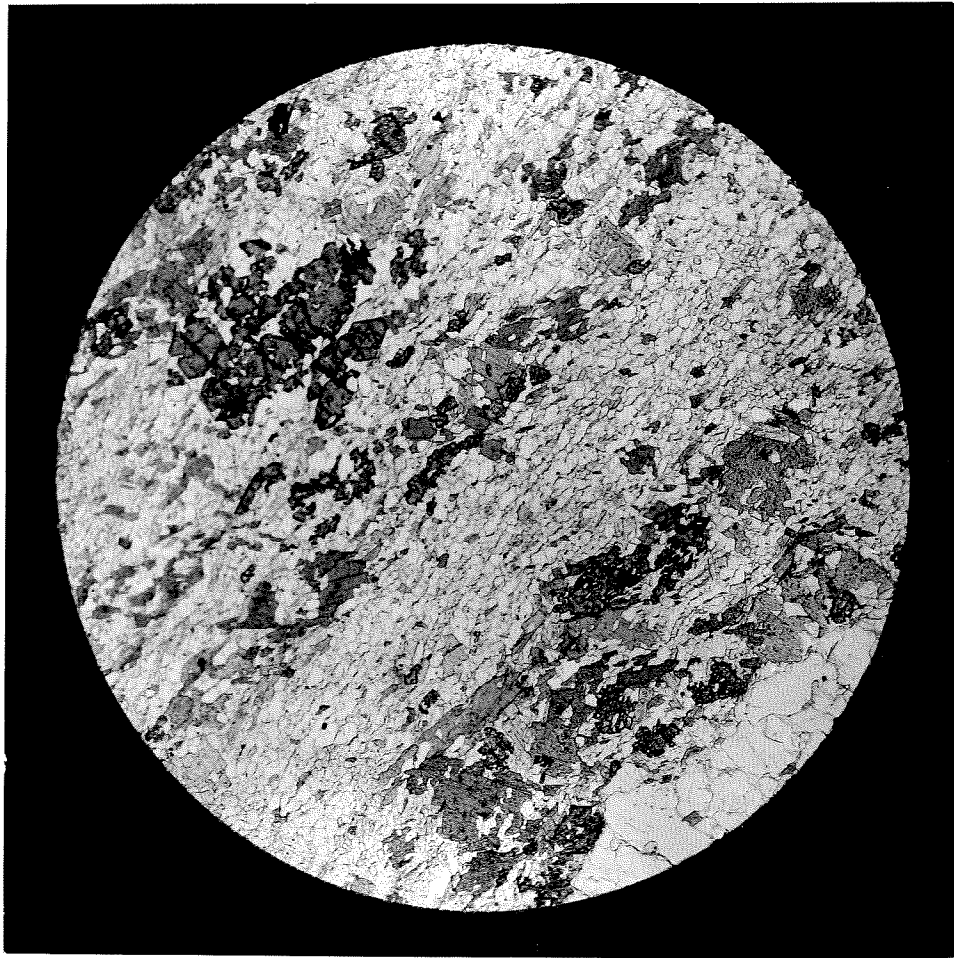


Fig. 2 - Photomicrograph of staurolite-biotite-quartz-schist showing (1) poeciloblastic staurolite and garnet with inclusions of quartz and (2) plates of mica, mostly biotite, orientated across the foliation. (Plain light; X20)

altered to chlorite. Small, anhedral, equant crystals of quartz with simple contacts form a granuloose aggregate that makes up the bulk of the matrix. Quartz also occurs in attenuated bands or lenses that are relatively free from magnetite, graphite and muscovite. Irregular to subhedral crystals of garnet, with a maximum diameter of three millimeters, are commonly present but only in small quantities. They usually have inclusions of quartz. Muscovite is a minor constituent as small plates with helizitic structures. Feldspar is rarely observed.

Amphibolite-Schist. Amphibolite-schists outcrop in many parts of the mapped and surrounding areas. They occur in outcrops along the northwest-southeast-trending border of the Swakane facies at Mad and Cougar Creeks, west of Miners Creek, southeast of Sugarloaf Peak, south of McCall Mountain along Big Meadow Creek, and on the south slope of Dirty Face Peak at the contact with the rocks of the Chelan facies. They are present west of the mapped area along Nason Creek and east of Tumwater Mountain. "Amphibolite-schist is very abundant along the border of the belt near the contact with the Chelan batholith. . . ." in Chelan quadrangle (Waters, 1932). Amphibolites are also included in the "granitic" rocks of the Chelan facies. These vary in size and shape and are distributed throughout the mapped area of this facies. It is important to note that the inclusions have a common foliation with the enclosing "granitic"

gneiss. Inclusions of amphibolite have also been reported by Waters (1932) in the rocks of the "Chelan batholith."

The amphibolite-schists are sometimes intercalated with lenses of marble (Waters, 1932 and Chappell, 1936). They are associated and transitional with crystalline schists of both the Swakane and Chelan facies. These interesting and important relationships are treated in detail elsewhere.

Megascopically, the amphibolite-schists are dark gray, medium-grained, schistose rocks consisting predominantly of grayish-black hornblende with variable quantities of small, subhedral to anhedral, red garnets. Frequently, they have minute, light gray seams of quartz and feldspar occurring along the surfaces of foliation which gives a "pin-stripe" appearance to sections that are transverse to the foliation. The surfaces of foliation may be planar or occasionally crenulated.

Thin sections, when examined under the microscope, reveal a medium-grained, schistose aggregate chiefly of hornblende with subordinate and variable quantities of feldspar, epidote, quartz, sphene, garnet, biotite, magnetite and apatite named in the order of their decreasing abundance. The hornblende is present as aligned, subhedral to anhedral, elongate crystals with X greenish-yellow, Y dark olive, and Z dark to bluish-green with Z making an angle of 25° with c. The bluish-green variety is in the amphibolites that are in contact with the quartz-diorite gneiss of the Chelan facies. Anhedral crys-

tals of andesine that may be as calcic as An_{46} are always present. They are usually fresh, but may show some sericitization. Inclusions of hornblende and epidote are frequently observed with the latter being more common. Epidote may be abundant or rare. It may be present as aligned, anhedral to subhedral, elongate crystals, or as equant grains associated with quartz and andesine in small, granular bands. It has a maximum interference color of third-order green and may or may not be pleochroic. Sphene is a common constituent, and it is somewhat variable in its crystal habit, both irregular and wedge-shaped forms being present. Red garnet is usually present as small crystals of subhedral to anhedral habit. It frequently had inclusions of feldspar, quartz, and hornblende. Locally, it may be very abundant. Biotite is usually absent, but aligned plates and shreds of biotite with X yellow, Y and Z dark brown are sometimes observed. Euhedral to subhedral crystals of apatite may be observed in all sections, but it is found only in small quantities. Irregular grains and masses of magnetite are also rather common.

Biotite-Gneiss. In northeastern Chiwaukum quadrangle, biotite-gneiss is probably the most abundant rock type in the Swakane facies. In the area southeast of Maverick Peak, sparse outcrops make it possible only to infer its distribution, but, according to Waters (1932), biotite-gneiss is the staple rock type of the "Swakane gneiss." It is common at the base of the

south slope of Dirty Face Peak, on Nason Ridge, and north and south of Rock Creek.

The biotite-gneiss shows every degree of transition with the biotite-muscovite-quartz-schist. Its relationship to the biotite-muscovite-quartz-schist is best illustrated on Nason Ridge where the biotite-gneiss occurs as sheetlike masses that give rise to lit-par-lit structures. The foliation of the gneiss and schist has a common attitude. The biotite-gneiss is also transitional with amphibolite-schist, notably at the railroad bridge near the junction of Whitepine and Nason Creeks west of the mapped area. Here one may observe all degrees of gradation between the two types of rock. Rocks showing incipient transition have minute seams of feldspar along the planes of schistosity of the amphibolite-schist. Intermediate stages show skialiths (Fig. 4) - shadows of incompletely transformed amphibolite-schist (Goodspeed, 1948) - with undisturbed orientation. Advanced stages are without skialiths and are represented by a feldspar-rich, medium-grained, mica-gneiss. Along Corbaley Canyon in Chelan quadrangle, every degree of transition is found between biotite-gneiss, granodiorite-gneiss, and quartz-diorite-gneiss (Waters, 1932).

Megascopically, the biotite-gneiss (Fig. 3) has a granitic appearance. It is a medium-grained, gneissose rock consisting predominantly of feldspar and quartz with subordinate quantities of aligned plates of biotite and muscovite.

PLATE NO. 5

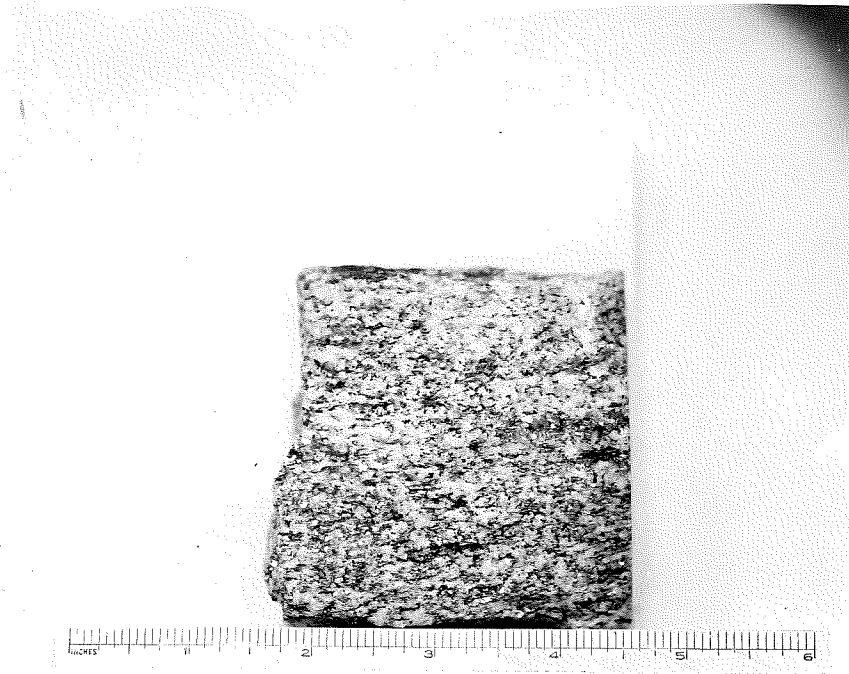


Fig. 3 - Photograph of hand specimen of biotite-gneiss.

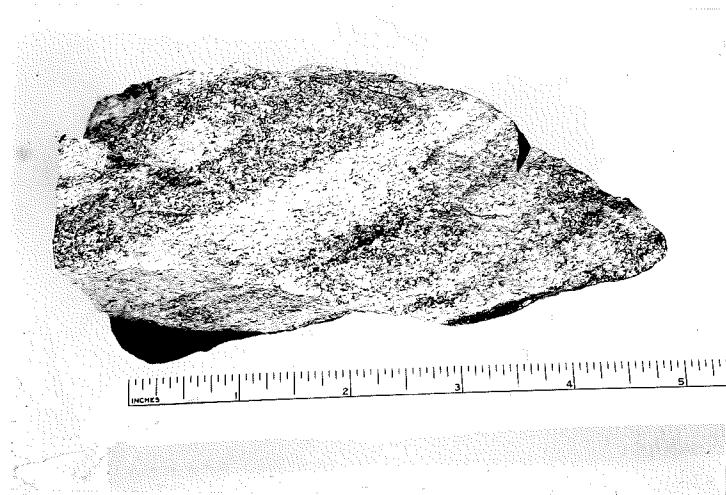


Fig. 4 - Photograph of hand specimen of biotite-gneiss with skialith.

In thin sections, the gneiss reveals a gneissose aggregate of plagioclase, quartz, biotite, and muscovite with minor and variable quantities of potash-feldspar, garnet, apatite, titanite, rutile, zircon, and chlorite. Calcic-oligoclase (An₂₇ to An₃₀) is the most abundant mineral and constitutes about half the rock by volume. It is present as interlocking, anhedral crystals with a maximum diameter of three millimeters. It is frequently replaced by orthoclase and microcline (Fig. 5), but these minerals are usually minor constituents of the rock. Quartz of anhedral habit is an abundant mineral, but it is subordinate to plagioclase. Its articulation with plagioclase may be moderately simple or complex with sutured contacts and myrmekitic intergrowths. Biotite occurs as moderately aligned plates and shreds with X yellow and Y and Z reddish-brown. It occasionally has inclusions of zircon surrounded by pleochroic haloes. It is usually fresh but may be altered to chlorite and magnetite. Muscovite may or may not be a common constituent, but it frequently exceeds the quantity of brown biotite. It is colorless and non-pleochroic with a 2V varying from approximately 15 to 0° (uniaxial). The plates may or may not show any alignment. A few, scattered, anhedral crystals of red garnet are common but rarely abundant. They frequently have inclusions of quartz, plagioclase, and biotite. Minute, euhedral to subhedral, six-sided crystals of apatite with prismatic habit are always present but only in small quantities.

PLATE NO. 6

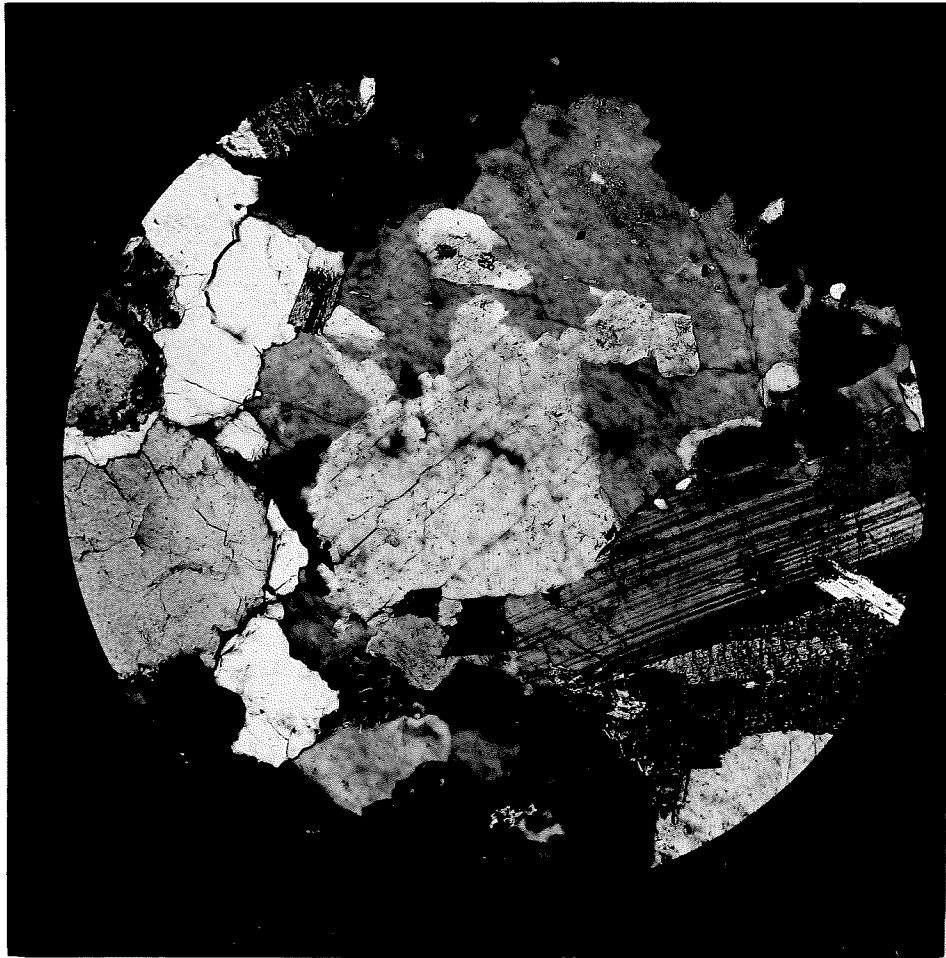


Fig. 5 - Photomicrograph of biotite-gneiss showing the replacement of calcic-oligoclase by microcline. (Under crossed nicols; X54)

Small irregular masses to euhedral crystals of sphene or rutile may be observed in nearly every section, but they are always a minor component of the rock.

Pegmatite and Associated Quartz Veins. Pegmatites and their associated milky quartz veins are distributed throughout the area occupied by the rocks of the Swakane facies. Lack of good exposures prevents an accurate account of their distribution, but there is an apparent increase in their abundance in the areas north and south of Rock Creek and in an elongate area west of Miners Creek and Sugarloaf Peak on the upper part of the composite or fault-line scarp. In the area to the southeast, pegmatites of the Swakane gneiss have been described by Waters (1932) and Chappell (1936).

There are two types of pegmatite veins in the mapped area. The feldspar of one type is plagioclase and in the other it is predominantly potash feldspar. The former type appears to be the more abundant. For the most part, the pegmatite veins are small, sill-like bodies that are parallel to the surfaces of foliation of the crystalline schists. They have an average thickness of about six to twelve inches, but they may be thinner or much thicker. The more attenuated pegmatite veins are not so simple in form and pass from one horizon of foliation to another to produce more complex patterns. As shown in the field, some of the pegmatites show a rather sharp contact with the crystalline schist, while others have a dis-

tinctly gradational contact. Thin, undisturbed relics of the country rock are often present in the pegmatites near their borders.

Milky quartz veins are frequently associated with the pegmatite veins. They commonly occur as a single vein or as a network of irregular veins within the pegmatites, but they may be transverse to them. In the latter case, an offset is sometimes apparent. They have an average thickness of about two inches, but veins six to eight inches in thickness have been observed.

The two types of pegmatite veins may be readily distinguished by stained polished surfaces or by microscopic examination of thin sections. The potash-feldspar pegmatite veins commonly consist of microperthite with subordinate quantities of quartz and plagioclase which makes up a coarse grained, seriated, complexly articulated aggregate. The microperthite is composed of orthoclase and albite and occurs as large, irregular crystals with inclusions of turbid, anhedral, relic crystals of plagioclase that have been sericitized in part. Quartz is present as anhedral crystals, and it occasionally shows myrmekitic intergrowths with the feldspar. Apatite is frequently present but only in minute quantities. Chlorite as an alteration product of biotite has been observed. The plagioclase pegmatite veins are composed of a coarse-grained, seriated aggregate of anhedral crystals of acidic

oligoclase with subordinate quantities of quartz and muscovite. Minor amounts of apatite, garnet and chlorite may or may not be present. The feldspar in the central portions of the pegmatites has a composition of An_{10} to An_{12} ; it has a composition of An_{17} at the contacts with the country rock. The contacts are gradational, and many relics of country rock occur in their original relative positions.

Talc-Carbonate-Rock. The talc-carbonate-rocks are present in two localities in the mapped area. The largest occurrence is an east-west, elongate, sill-like mass about one-tenth square mile in area approximately one-half mile northwest of the summit of Sugarloaf Peak. The other is a small outcrop one and one-fourth miles south of Maverick Peak on the ridge west of Miners Creek. Due to overburden and vegetation, their contact with the associated crystalline schists of the Swakane facies is not exposed.

In hand specimen on a fresh surface, the rock is a gray, compact aggregate of talc and dolomite with a few large, grayish-black, anhedral, cleavable crystals of enstatite or rhombic pyroxene. Unweathered surfaces have a waxy luster and a greasy feel. Weathered surfaces are brown to reddish-brown with iron oxide. A schistose structure is sometimes apparent.

Thin sections (Fig. 6) when examined under the microscope reveal a complex aggregate of talc, dolomite, enstatite, tremolite, antigorite, chlorite and iron ore, named in the

PLATE NO. 7

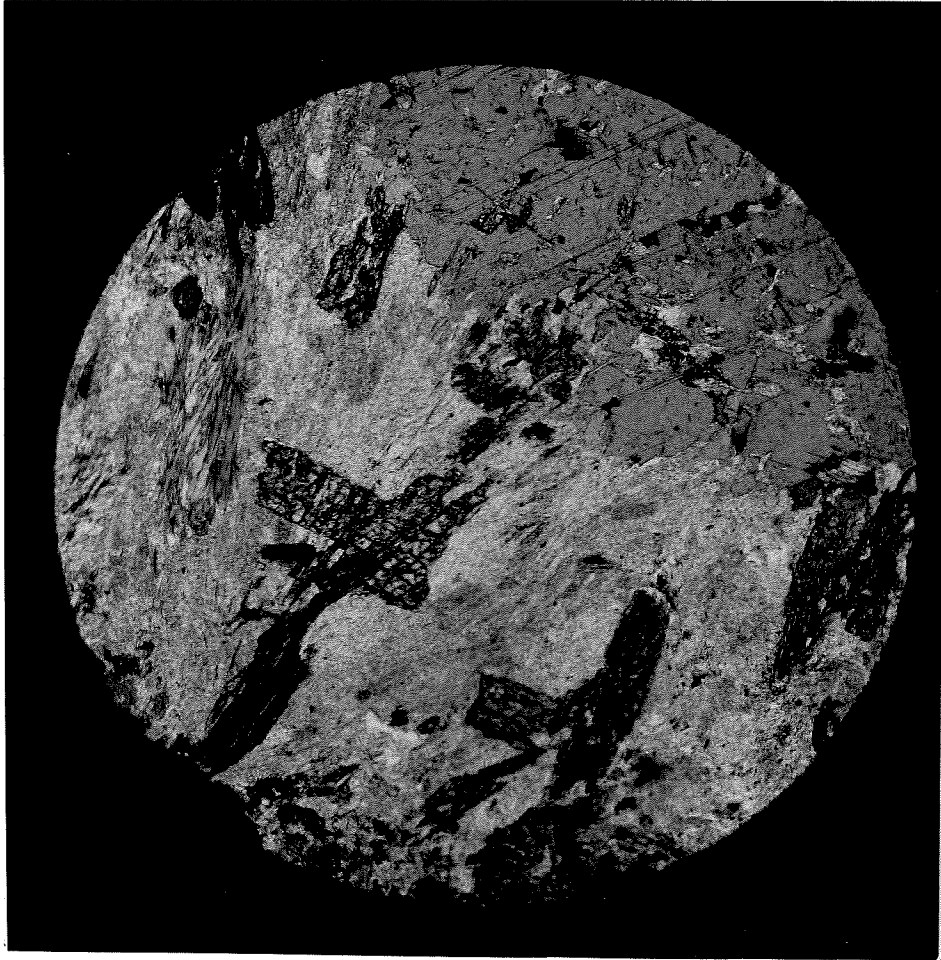


Fig. 6 - Photomicrograph of a talc-carbonate-rock with relics of enstatite. Other minerals are talc, dolomite, antigorite, and iron ore. (Under crossed nicols; X20)

order of the decreasing abundance. Relics of subhedral to anhedral crystals of enstatite are common. They are normally of prismatic habit and usually have a distinct pinacoidal parting or cleavage normal to the optic axial plane. The optic sign is negative, and $2V$ is nearly 90° which places the FeO content at about 14 to 17 per cent. Numerous inclusions of magnetite and some pyrite are regularly arranged on the surfaces of cleavage and parting with an optimum development on the pinacoidal parting. The enstatite shows some alteration to antigorite (bastite) which is geometrically orientated on the enstatite and sometimes pseudomorphous after it. Tremolite occurs as long bladed to acicular and fibrous crystals which are altered in part to talc. They are common in some sections but minor in others. Some chlorite is associated with the tremolite. It has the appearance of antigorite, but it is length-fast. The crystals of dolomite are of anhedral form and often show twinning lamellae parallel to the long diagonals of the rhombs. Talc occurs as fine platy aggregates which are of irregular outline. Talc and dolomite constitute the bulk of the rock. They have inclusions of all the other minerals and of each other. They were the last minerals to form.

Marble. The areal extent of the marble is small, but pods of marble are present in several localities in the mapped area. North of Maverick Peak, small pods of white, fine to medium-grained marble are intercalated with amphibolite-schists,

and near the base of the composite or fault-line scarp at Marble Creek, a large inclusion of white, aphanitic marble occurs in the "granitic" rocks of the Chelan facies. The contact between the inclusion and host rock is not exposed. In the area to the southeast in Chelan and Wenatchee quadrangles, lenses of marble are intercalated with amphibolite-schist, and mica-gneiss (Waters, 1932 and Chappell, 1936). Waters (1930) also described two large "roof pendants" of white, aphanitic marble in the Chelan batholith. These two inclusions along with the one on Marble Creek form a northwest-southeast trend and may be relics of the same calcareous belt.

In thin section, the marble shows a very simple mineral assemblage with granulose structures and granoblastic textures. The white, medium-grained marble consists almost entirely of anhedral grains of calcite which commonly show lamellar twinning and a certain amount of interlocking. Small, angular to rounded grains of quartz are occasionally enclosed in the calcite crystals. The white, aphanitic marble is composed of a very fine-grained aggregate of anhedral crystals of calcite. Lamellar twinning is not common.

Poorly preserved fossils or fossil-like forms have been observed in several of the pods of marble. They have been examined by four geologists without complete agreement. Three determined them to be relic fossils and the other considered them to be deformed quartz pebbles.

Chelan Facies

Rocks of the Chelan facies occupy a large area that includes McDonald Ridge of the Entiat Mountains and a small area on Dirty Face Peak. Their regional distribution is not completely known, but they have been mapped and described by Waters (1930) in the southern half of Chelan quadrangle and have been traced by the author along the Entiat River as far north as Three Creek.

Rocks of the Chelan facies are divided into three sub-facies which are quartz-diorite-gneiss, granodiorite-gneiss, and diorite subfacies. The distribution, occurrence and descriptive petrology of these rocks will be discussed in the following sections.

Quartz-Diorite-Gneiss Subfacies. Quartz-diorite-gneiss is the staple rock type of the Chelan facies, constituting about 93 per cent of the facies in the area under consideration. Its regional distribution is unknown, but rocks of this type were observed by the author along the Entiat River between Three Creek and the Columbia River.

Megascopically, the quartz-diorite-gneiss consists of a coarse-grained, gneissose aggregate of anhedral crystals of white feldspar and subordinate quantities of quartz (between 10 and 15 per cent by volume) with moderately aligned trains of anhedral crystals or crystal aggregates of black hornblende and biotite. The gneissose structure (Fig. 7) is readily seen in

PLATE NO. 8

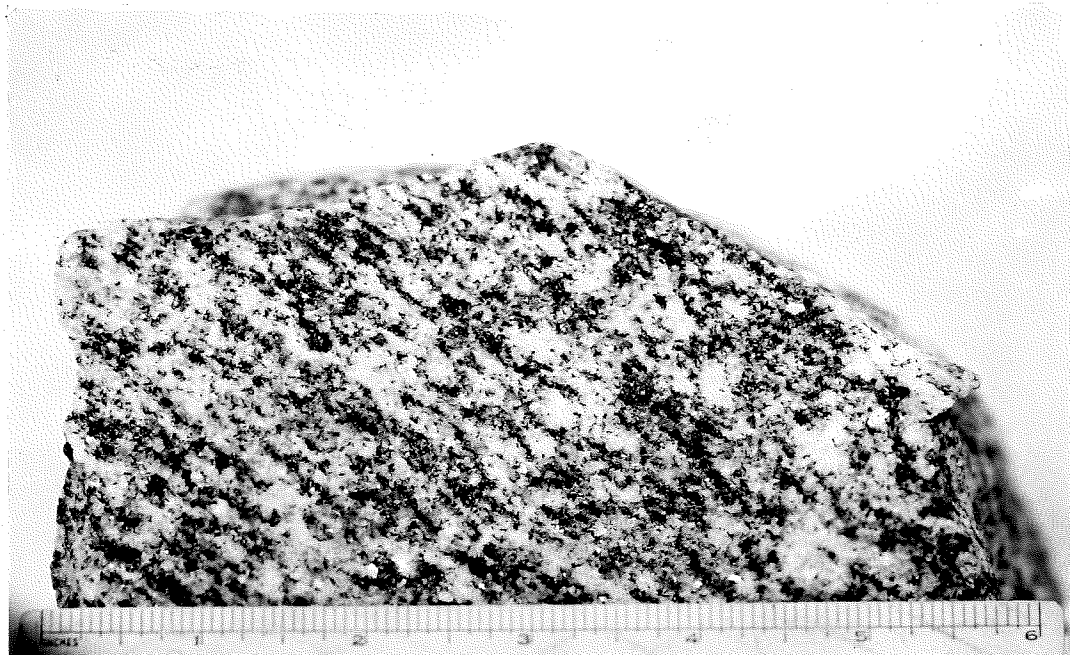


Fig. 7 - Photograph of a hand specimen of quartz-diorite-gneiss.

the field or in large specimens, but is less apparent in small specimens.

Thin sections, when studied under the microscope, reveal a coarse-grained, gneissose aggregate of feldspar, hornblende, and biotite with subordinate quantities of quartz, epidote, sphene, apatite, and magnetite. Feldspar is the most abundant mineral and occurs as seriated, anhedral to subhedral crystals with moderately interlocking contacts. It varies in composition from calcic-oligoclase (An_{27}) to sodic-andesine (An_{37}), the latter being common only at or near contacts with amphibolites of the Swakane facies or the amphibolite inclusions within the quartz-diorite-gneiss. The feldspar is occasionally zoned with cores of more calcic composition than the rims. Usually it is fresh and clear, but it may show various degrees of turbidity and sericitization. Epidote is often the most common inclusion but small crystals of hornblende, biotite, apatite, sphene, and magnetite may also be observed. Hornblende is present as moderately aligned trains of anhedral, elongate crystals with X greenish-yellow, Y dark olive-green, and Z dark to bluish-green with c making an angle of 26° with Z. It may be the most abundant mafic mineral (Fig. 8) or subordinate to biotite (Fig. 9) with which it is inversely proportional. Biotite, with X yellow and Y and Z dark brown to opaque, occurs as moderately aligned aggregates of unorientated flakes and plates of anhedral habit. It may be unaltered or

PLATE NO. 9

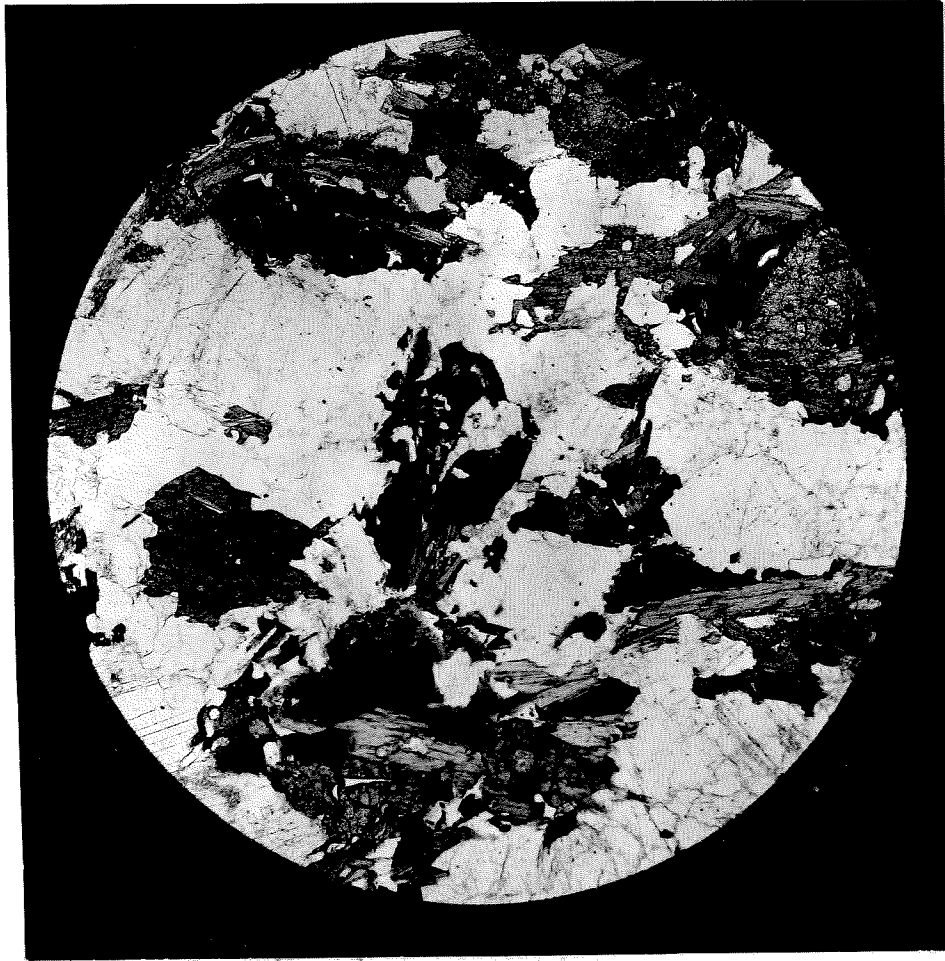


Fig. 8 - Photomicrograph of quartz-diorite-gneiss 3 1/2 miles north of contact on the Entiat Mountains. Hornblende is the dominant mafic mineral and is in close association with subordinate quantities of biotite and epidote. The other minerals are feldspar (An_{28}), quartz, sphene and apatite. (Plain light; X20)

PLATE NO. 10

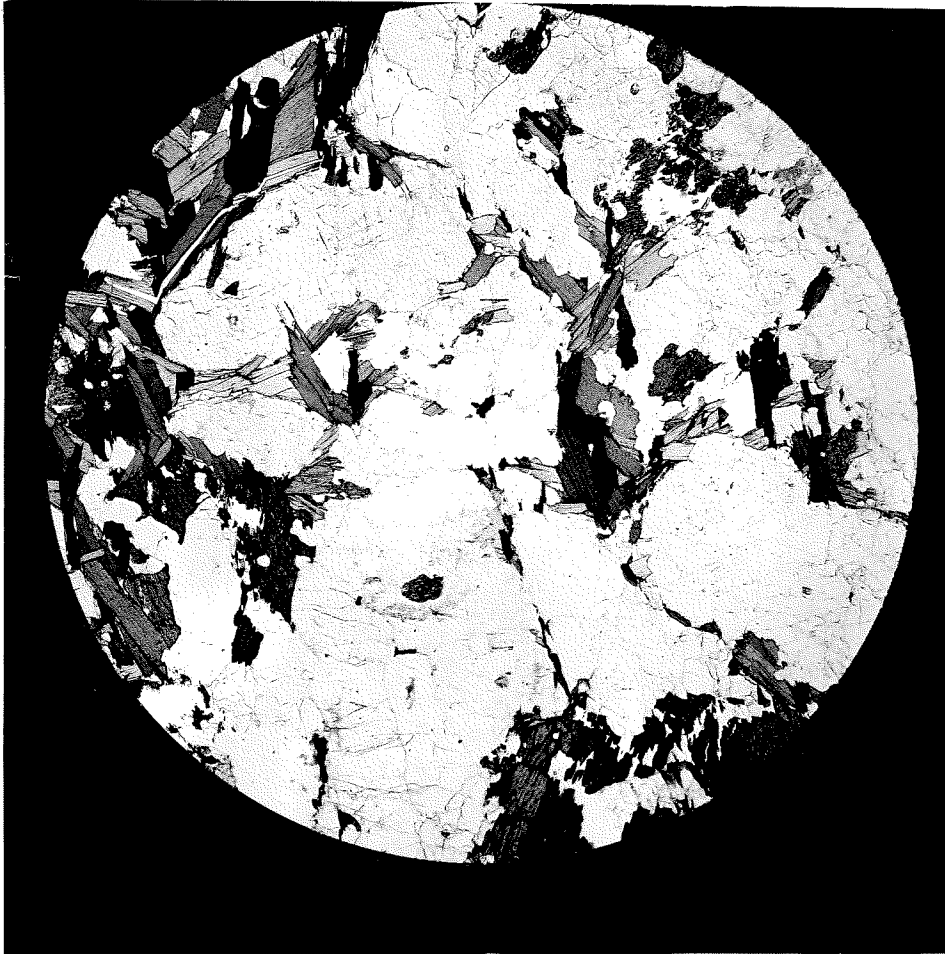


Fig. 9 - Photomicrograph of quartz-diorite-gneiss four miles north of contact on the Entiat Mountains. Hornblende is subordinate to biotite. (Plain light; X20)

altered to chlorite. Epidote is a common constituent of the rock, and occurs as subhedral to anhedral, elongated, pleochroic crystals with Y pale greenish-yellow, and X and Z colorless. It is optically negative with a 2V or approximately 85° and the optic axial plane normal to the trace of the cleavage. It is in close association with hornblende and biotite, and it frequently has well developed crystal faces in contact with the latter mineral (Figs. 8, 13 and 24). Quartz is interstitial and occasionally shows myrmekitic intergrowths with feldspar. It is always present and constitutes between 10 and 15 per cent of the rock by volume. Sphene is commonly associated with hornblende and biotite as irregular to wedge-shaped crystals with brown to dark brown pleochroism. Minute, euhedral to subhedral, six-sided, prismatic crystals of apatite are always present, but they are found only in small amounts. Minor quantities of irregular masses to subhedral crystals of magnetite are associated with crystals of hornblende and biotite.

Inclusions of dark gray, medium-grained, porphyroblastic amphibolite are common throughout the rocks of the quartz-diorite-gneiss subfacies. They are on crests, slopes, and in the valleys where they could not possibly have been connected with the parent rock. They have gradational contacts and a common foliation with the enclosing quartz-diorite-gneiss. The inclusions may be lenticular or irregular in shape and may

range in maximum dimensions from a few inches to several feet.

Thin sections of the inclusions, when examined under the microscope are seen to consist of medium-grained, gneissose aggregates of hornblende, biotite, feldspar, epidote, and quartz with minor quantities of sphene, apatite and iron ore. Hornblende, with X yellow, Y dark olive, and Z bluish-green with Z making an angle of 25° with c is present as moderately aligned crystals with elongated, anhedral forms. It is the most abundant mineral and is closely associated with subordinate quantities of biotite, epidote, sphene and iron ore. Feldspar, the second most abundant mineral, has a composition of An₃₈ which is nearly the same as the feldspar (An₃₆) of the adjacent and enclosing quartz-diorite-gneiss. Most of the feldspar is in the matrix as anhedral to subhedral crystals, but anhedral to subhedral porphyroblasts (Fig. 11) with a maximum diameter of seven millimeters are numerous. Inclusions of epidote, hornblende, biotite, apatite, and sphene, with epidote being the most common, are always in the porphyroblasts but may or may not be in the smaller crystals of feldspar. Plates and anhedral crystals of biotite, with X yellow and Y and Z dark olive-brown to opaque, are abundant and aligned parallel to the crystals of hornblende. Subhedral to anhedral crystals of epidote with prismatic habit are common. They are slightly pleochroic with Y pale yellowish-green and X and Z colorless and have a maximum interference color of third-order green. Quartz

PLATE NO. 11

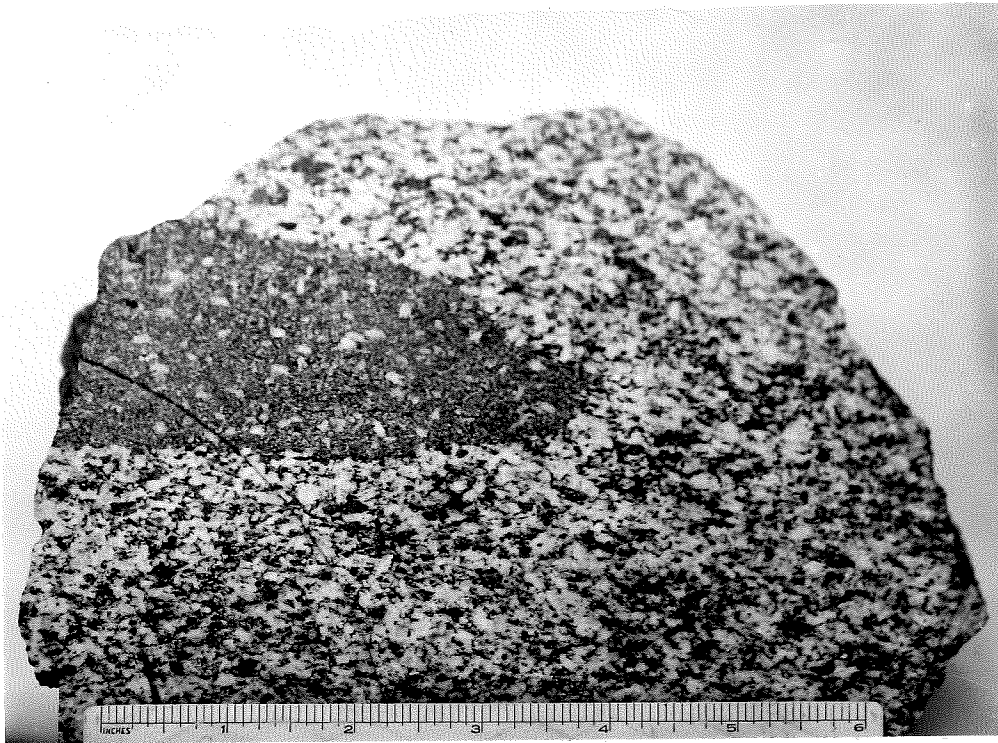


Fig. 10 - Photograph of quartz-diorite-gneiss with inclusion (skialith) of amphibolite. Specimen collected on west slope of Cougar Mountain.

PLATE NO. 12

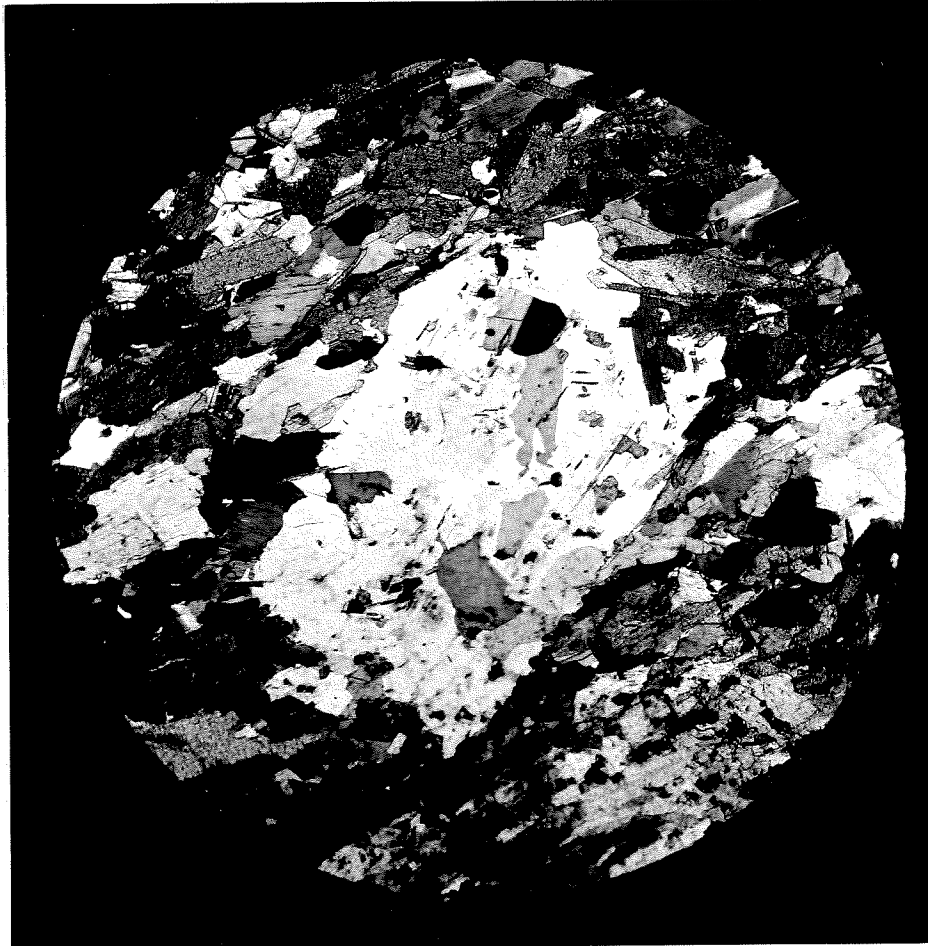
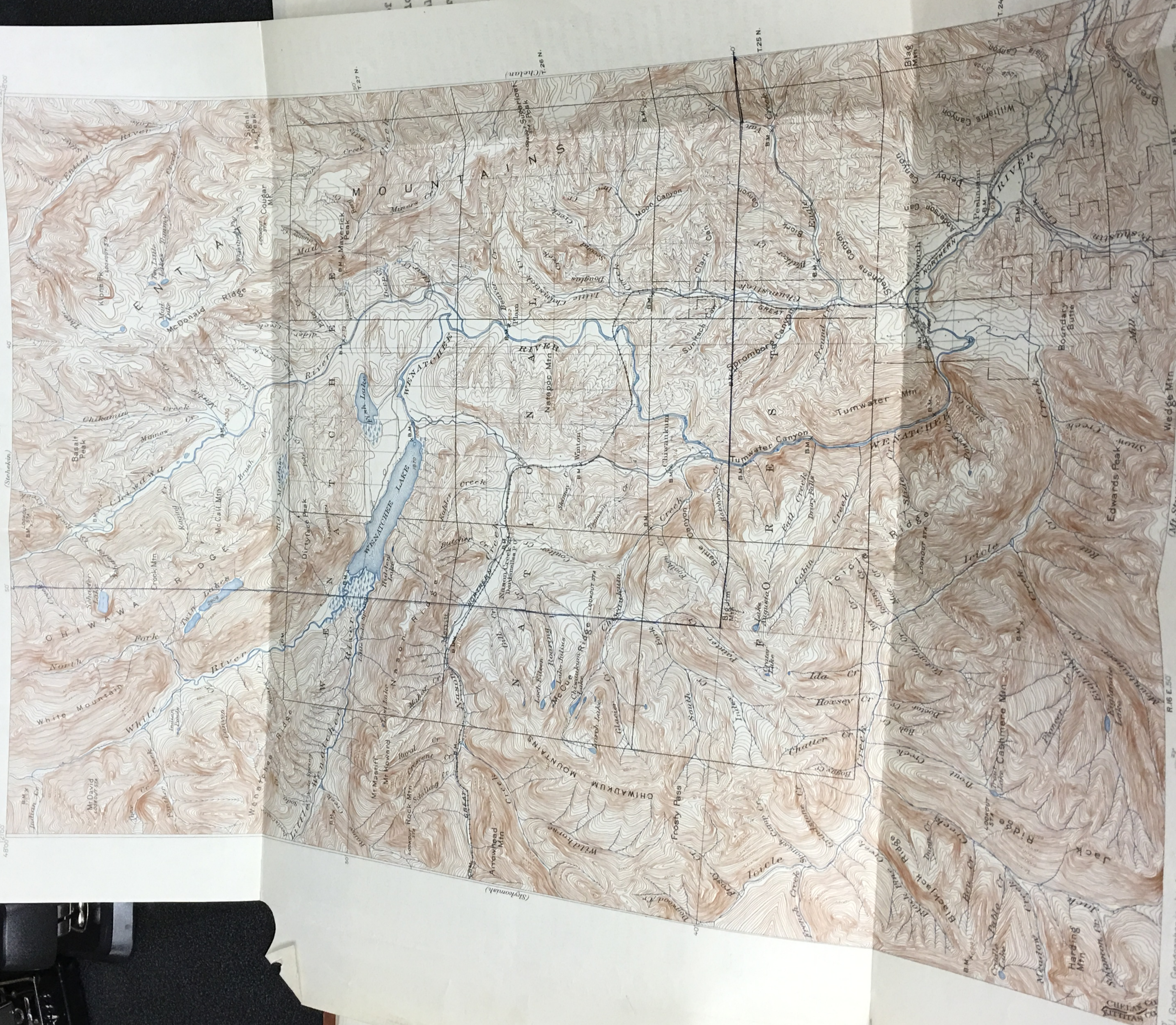


Fig. 11 - Photomicrograph of the skialith in Fig. 10 showing porphyroblast of feldspar (An₃₈) with inclusions of epidote, plagioclase, biotite and hornblende. (Under crossed nicols; X20)

ESS JHN70

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY
WASHINGTON (CHELAN COUNTY) CHIAWADKUM QUADRANGLE
PLATE NO. 2



Scale 1:25000
Scale interval 100 feet
Datum is mean sea level.
METSKER 1020 - BR SEATTLE
Edition of Mar. 1904. Reprinted 1943
Polyconic projection
CHIAWADKUM, WASH.
N. 47° 30' W. 122° 30' E.
Triangulation in charge by U. S. Geode Geographer
Topography by A. H. Sylvester
Surveyed by R. A. Farmer
Railroad from Winton to Peashton added from information by Great Northern R.R.

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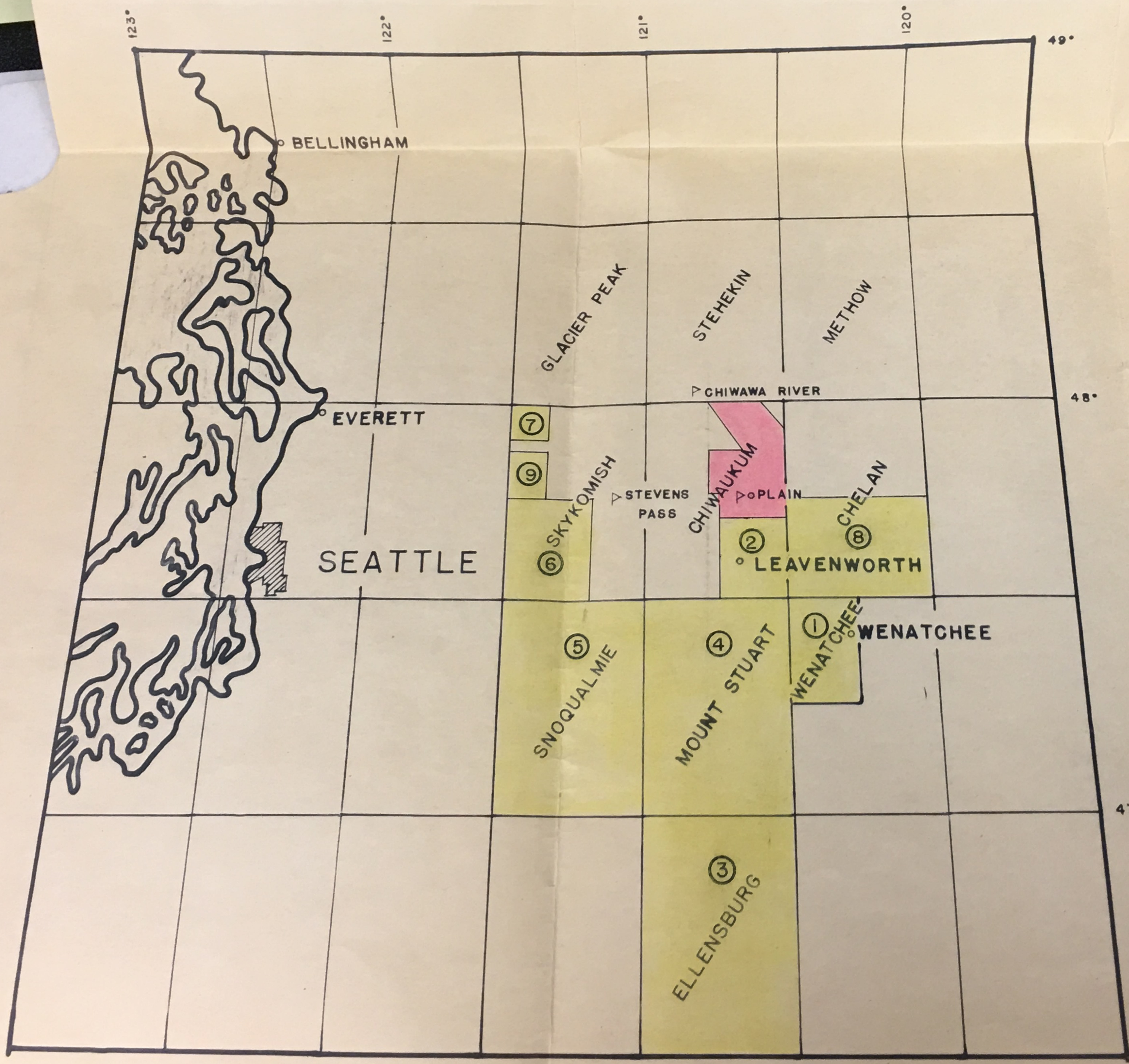


Plate No. 1.

LEGEND

- AREA UNDER CONSIDERATION
- PREVIOUSLY MAPPED AREAS
- (1) CHAPPELL, W.M. (1936)
- (2) PAGE, B.M. (1939)
- (3) SMITH, G.O. (1901)
- (4) SMITH, G.O. (1904)
- (5) SMITH, G.O. AND CALKINS, F.C. (1906)
- (6) SMITH, W.S. (1915)
- (7) SPURR, J.E. (1900-01)
- (8) WATERS, A.C. (1930)
- (9) WEAVER, C.E. (1912)

CITIES AND TOWNS

WEATHER STATIONS

SCALE 0 10 20 30 40 MILES

of anhedral habit constitutes less than 3 per cent of the rock by volume. Sphene is a minor constituent, and is present as anhedral masses of wedge-shaped crystals with a pleochroism of brown to dark brown. Minute, euhedral to subhedral, prismatic crystals of apatite are scattered throughout the rock but only in small quantities. The iron ore is present as anhedral crystals of magnetite which is sometimes altered to hematite.

The similarity of mineral assemblages and of the characteristics of the individual minerals in the amphibolite inclusions and enclosing quartz-diorite-gneiss should be noted. (Figs. 12 and 13.) Feldspar (An_{37} to An_{38}), hornblende, biotite, epidote, quartz, sphene, apatite and iron ore are common to both. The apparent difference is their relative abundance. In the quartz-diorite-gneiss there is a conspicuous increase in the quantity of feldspar and quartz, a small increase in epidote, and a marked decrease in the mafic minerals with a relative increase of biotite over hornblende. The other minerals are minor constituents and their changes in amount are not so apparent.

At the observed contacts between rocks of the Chelan and Swakane facies, notably at the junction of Mad and Jimmy Creeks, quartz-diorite-gneiss grades into amphibolite-schist. (Figs. 14, 15, 16, 17 and 18.) They have a common foliation and show every degree of transition with each other. Bands of medium to coarse-grained gneiss that vary from a fraction of an

PLATE NO. 13

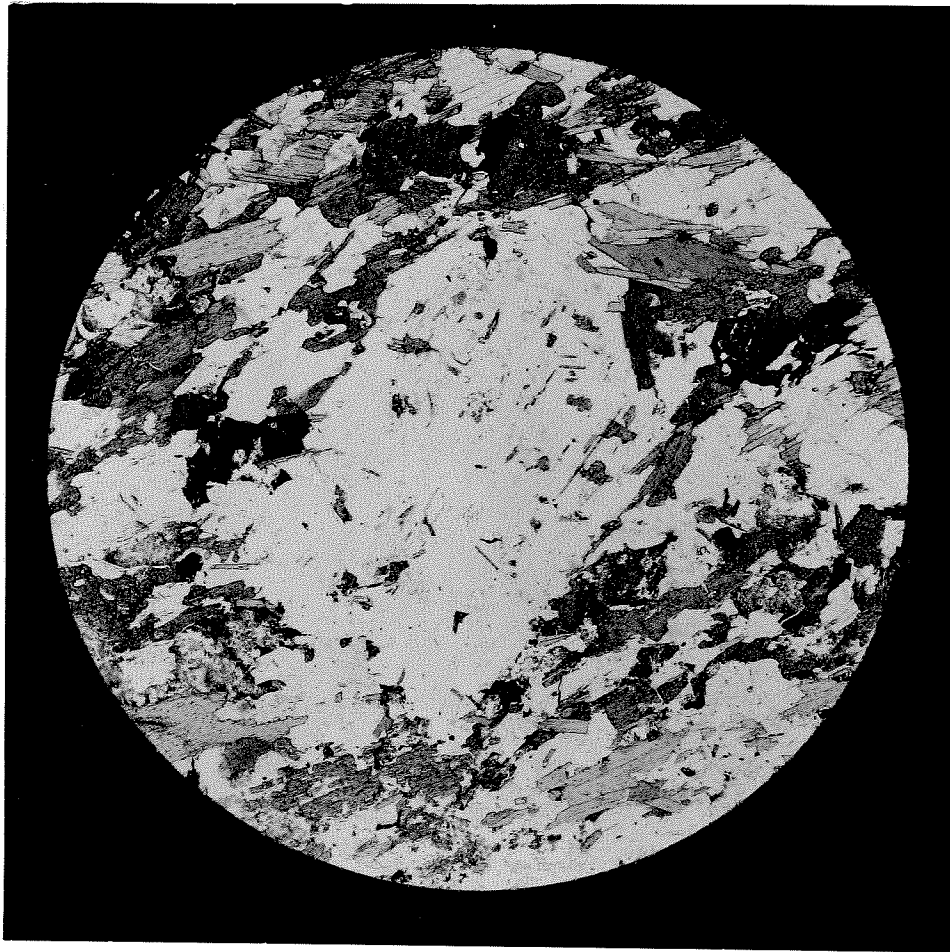


Fig. 12 - Photomicrograph of skialith in Fig. 10 showing the mineral composition and crystallo-
blastic textures. The minerals are feldspar
(An₃₈), hornblende, biotite, epidote, sphene,
quartz, and apatite. Compare with Fig. 13.
(Plain light; X20)

PLATE NO. 14

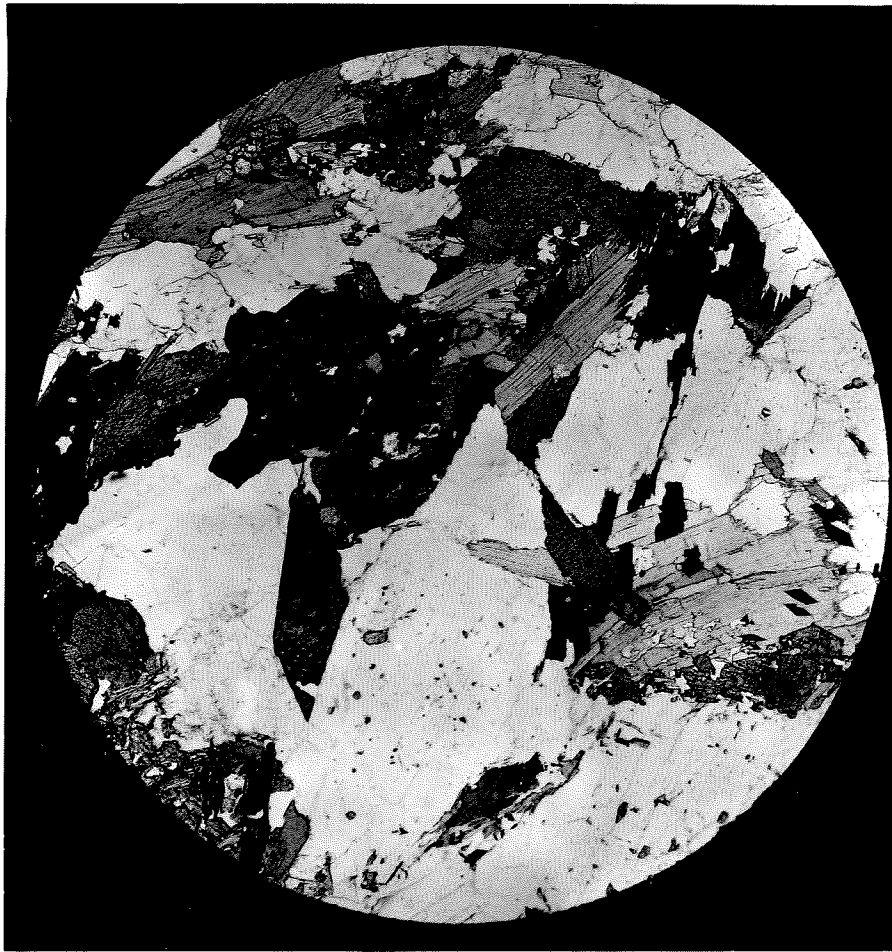


Fig. 13 - Photomicrograph of quartz-diorite-gneiss in Fig. 10 showing the mineral composition and textures. The minerals are feldspar (An_{36}), hornblende, biotite, quartz, epidote, sphene and apatite. Note the close relationship between the mineral composition and textures of the host rock and skialith (Fig. 12). (Plain light; X20)

PLATE NO. 15

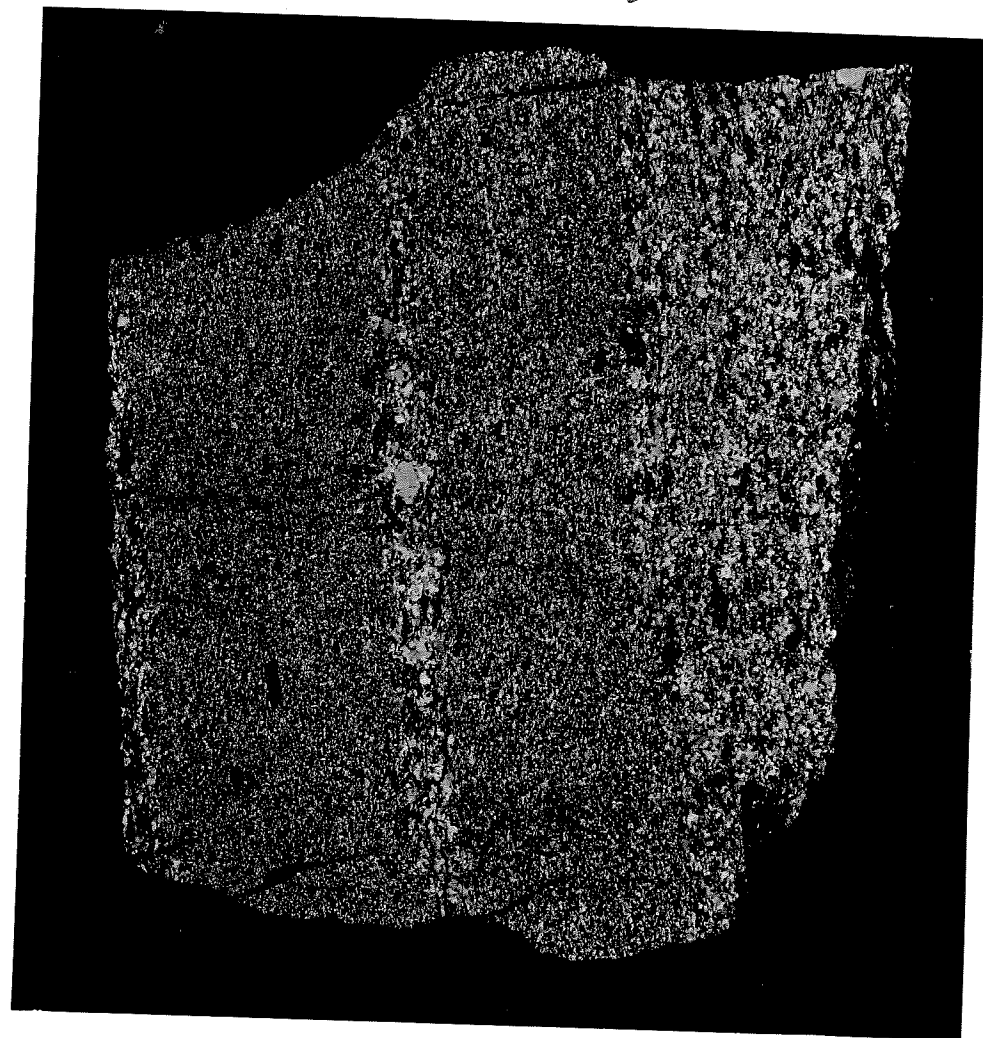


Fig. 14 - Photograph of a large thin section (3 1/4 by 4 inches) showing the gradational contact between amphibolite schist and quartz-diorite-gneiss. (Under crossed nicols; X 1 1/4)

PLATE NO. 16

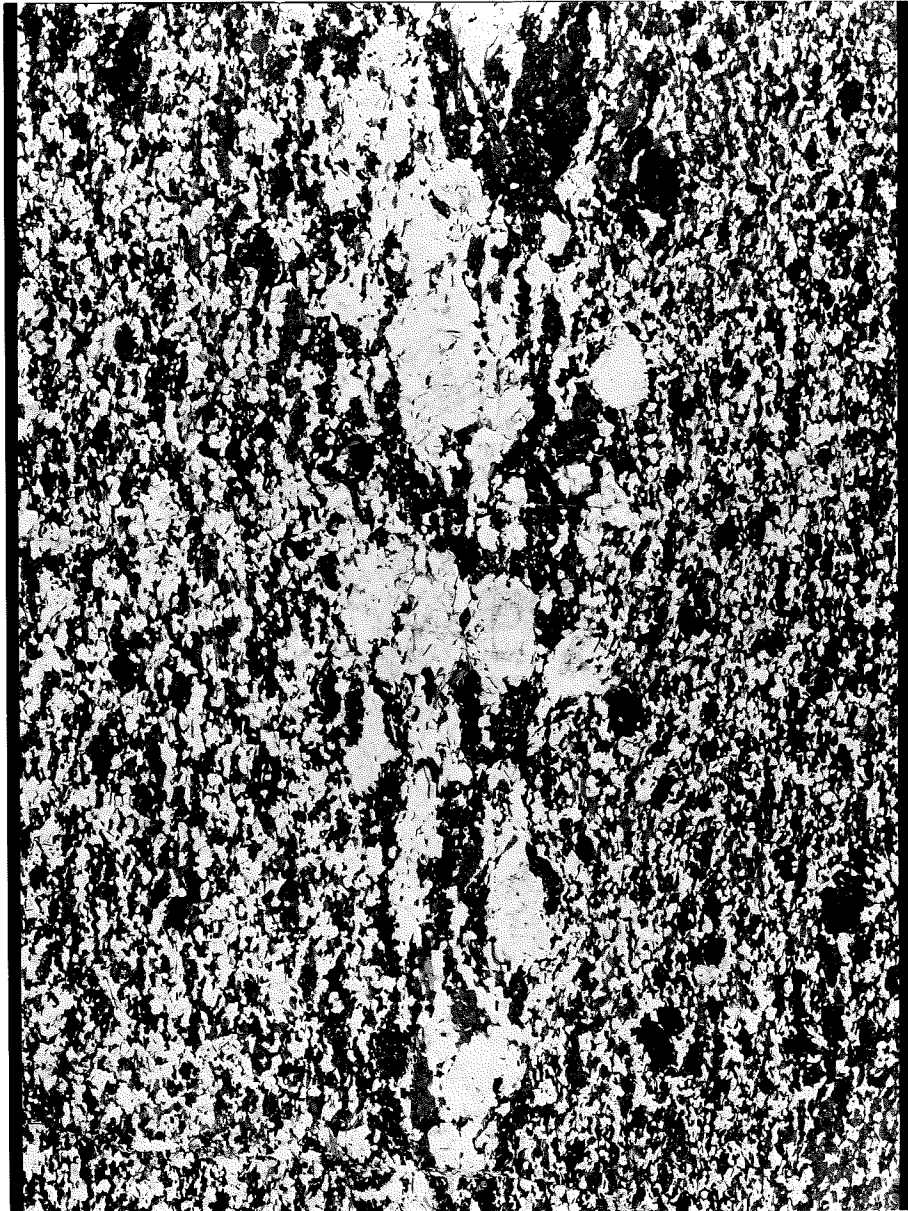


Fig. 15 - Photomicrograph (X5) of small granitic band in Fig. 14 showing porphyroblasts of feldspar and gradational contacts with the enclosing amphibolite schist. (Plain light)

PLATE NO. 17

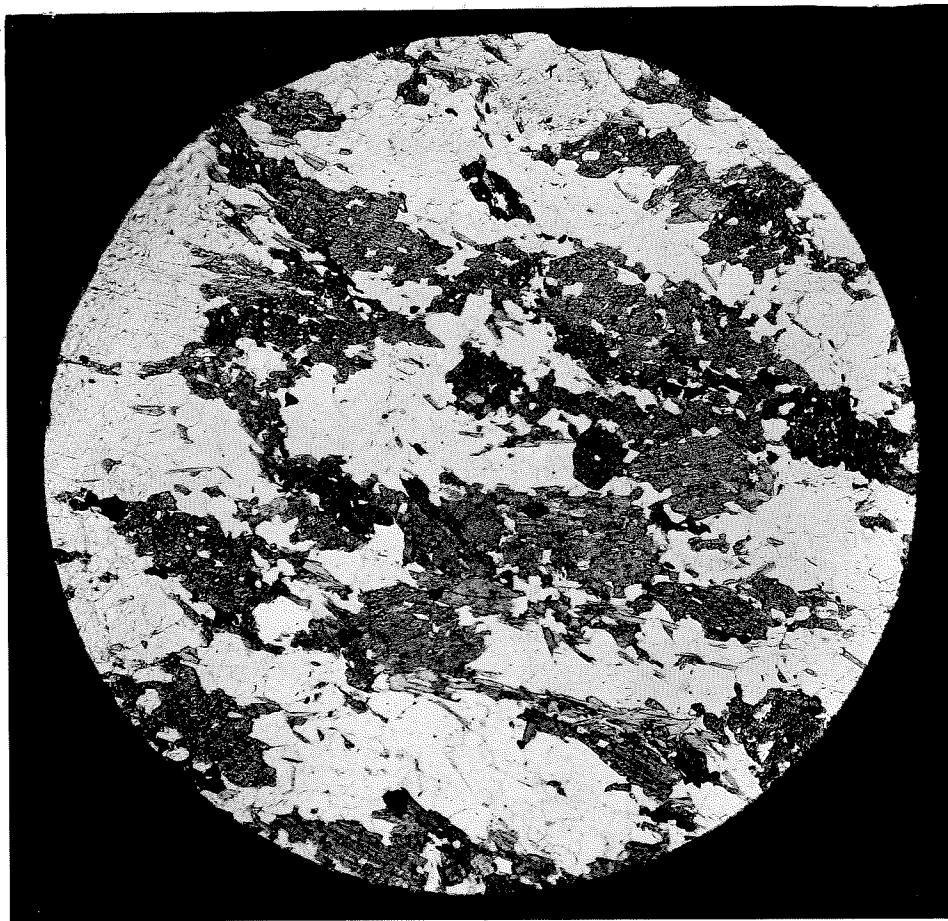


Fig. 16 - Photomicrograph (X20) of the large granitic band in Fig. 14 showing crystalloblastic textures. The minerals are feldspar (An_{36}), hornblende, biotite, quartz, epidote, apatite and iron ore. (Plain light)

PLATE NO. 18



Fig. 17 - Photograph of hand specimen showing granitic bands with porphyroblasts of feldspar in amphibolite-schist. See Fig. 14 for large thin section of specimen.



Fig. 18 - Photograph of hand specimen showing more advanced development of porphyroblasts of feldspar in amphibolite-schist.

inch to several feet in thickness are parallel to the foliation of the schist to give a lit-par-lit structure. The more attenuated bands may pass into a linear series of small, isolated porphyroblasts of feldspar along the foliation. Feldspar porphyroblasts may also be scattered at random in zones that grade into bands of quartz-diorite-gneiss as their abundance increases. The increase in feldspar is accompanied by an increase in biotite, quartz and sometimes epidote with a corresponding decrease in the amount of hornblende which becomes subordinate in quantity to feldspar. Relics of undisturbed schist are frequently observed in the bands of gneiss. The schist and gneiss have a common mineral assemblage of hornblende, feldspar, biotite, epidote, sphene, apatite, and iron ore with the only apparent difference being in the relative quantities of the minerals and in the anorthite content of the feldspar. In the schist, the feldspar has a composition of An_{42} which grades to An_{36} in the gneiss. The other minerals have the same characteristics in both types of rocks.

According to Waters (1932), every degree of transition is observed between granodiorite-gneiss and biotite-gneiss in passing down Corbaley Canyon in Chelan quadrangle. Waters further noted that the biotite-gneiss is considerably richer in quartz than the "granitic" gneiss at the head of the canyon.

Granodiorite-Gneiss Subfacies. Granodiorite-gneiss was observed in scattered outcrops east of Mad Creek between Two

Little Lakes and Whistling Pig Creek. From these outcrops, the areal distribution is inferred as comprising 5 per cent of the area of the Chelan facies. It always occurs within the quartz-diorite-gneiss with which it has a common foliation and shows every degree of transition.

Megascopically, the rock (Fig. 19) is a light gray, coarse-grained, gneissose aggregate consisting dominantly of feldspar with subordinate quantities of quartz and aligned plates of biotite and muscovite. It is frequently prophyroblastic with anhedral crystals of feldspar, with a maximum diameter of 20 millimeters, scattered at random or along the foliation to give the rock a banded appearance.

A study of stained polished-sections and microscopic examination of thin sections shows that the rock consists of a coarse-grained, gneissose assemblage of variable quantities of oligoclase, microcline, orthoclase, quartz, muscovite, biotite, epidote, sphene, apatite and iron ore. Oligoclase is the most abundant mineral, but it has a variable and inverse ratio with potash feldspar which may constitute as high as 40 per cent of the feldspar by volume. Oligoclase has a composition of An_{27} and may have a wide range of potash feldspar. The crystals of oligoclase are of anhedral habit with moderate to complex articulation, the latter being with irregular crystals and porphyroblasts of microcline (Fig. 20) and orthoclase which have replaced the oligoclase with the development of embayments and

PLATE NO. 19



Fig. 19 - Photograph of hand specimen of granodiorite-gneiss showing foliation and light colored bands rich in potash feldspar.

PLATE NO. 20

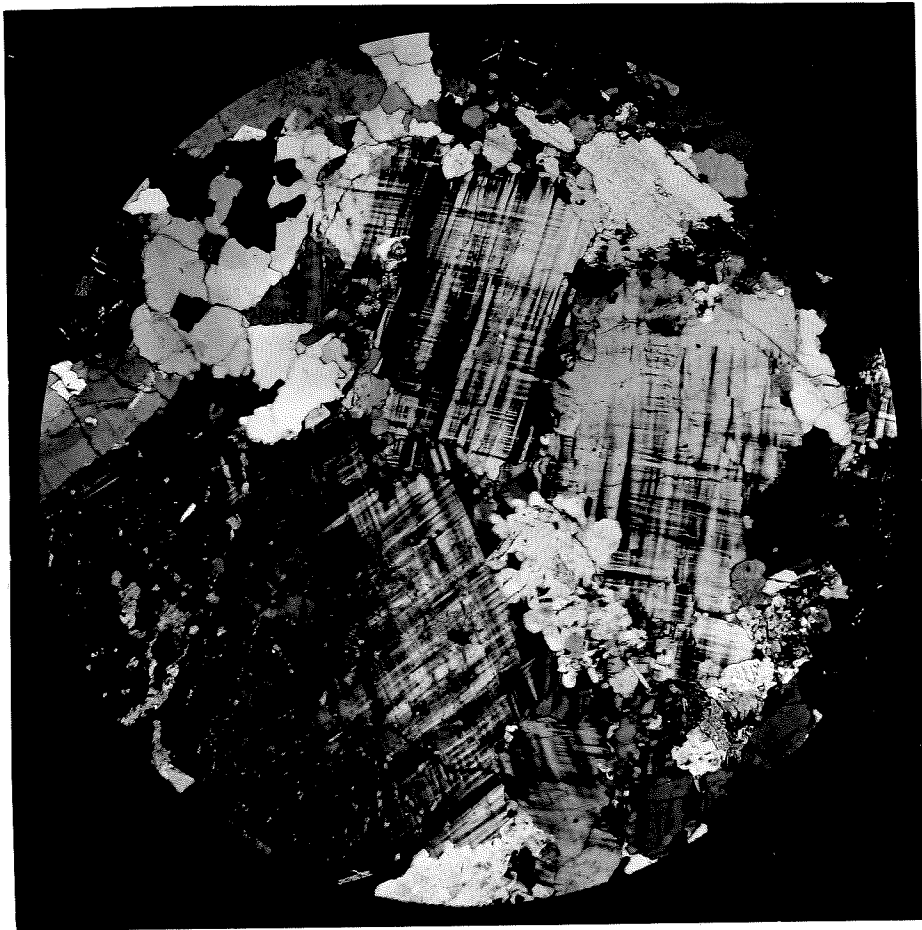


Fig. 20 - Photomicrograph of granodiorite-gneiss with porphyroblasts of microcline.

vermicular intergrowths. At and near the contacts with the quartz-diorite subfacies, the potash feldspars occur in bands parallel to the foliation, and within the mass, it may become evenly distributed throughout the rock. Quartz occurs as anhedral crystals with interlocking contacts. In the specimens collected, there is a definite increase in the quartz content, which may be 25 per cent of the rock by volume, as the quantity of potash feldspar increases. Muscovite (including sericite) is also present in variable quantities that increase and decrease with the potash feldspar content. It is usually associated with oligoclase but is frequently observed with quartz, orthoclase, microcline, biotite, chlorite and iron ore. It occurs as plates and shreds that are commonly vermiculated. It has a 2V that ranges from 20 to nearly 60° and a maximum interference color of second-order green. Biotite, with X yellow and Y and Z dark olive to opaque, is present as plates and shreds which are sometimes altered to another variety of biotite, with X yellow and Y and Z bright green, and to chlorite. Epidote is present as subhedral to irregular crystals with Y yellowish-green and X and Z colorless. It usually occurs where potash feldspar has replaced oligoclase and biotite, but it is only common in those rocks that have a low percentage of potash feldspar. Sphene is also only common in those rocks with a small percentage of potash feldspar and occurs as anhedral to wedge-shaped crystals. Small quantities of euhedral to sub-

hedral crystals of apatite with prismatic habit are always present. Irregular masses to subhedral crystals of magnetite may be observed in all sections of the rock.

Diorite Subfacies. Diorite is present in a few scattered outcrops west of the lookout station on Klone Peak. It comprises less than 1 per cent of the area of the Chelan facies but may have a greater distribution in the unmapped area to the north. A transition in textures, structures, and mineral composition with the quartz-diorite-gneiss is inferred by differences in the outcrops, but a continuous transition between the two rock types was not observed.

Megascopically, the rock is a gray, medium-grained, granulose to slightly gneissose aggregate of nearly equal volumes of feldspar and hornblende. As it grades into quartz-diorite-gneiss, the percentage of hornblende decreases with a corresponding increase in the quantity of feldspar and the appearance of quartz and biotite.

When examined under the microscope, thin sections exhibit a granulose to slightly gneissose, medium-grained aggregate dominantly of feldspar and hornblende with minor quantities of magnetite, apatite, epidote, chlorite, biotite, quartz, fluorite and sphene. Feldspar occurs as subhedral to anhedral crystals with moderately interlocking contacts. It has a composition of An₃₈ to An₄₂ and occasionally shows zoning with cores of more calcic composition. It is usually fresh,

but it may show a trace of sericitization. Feldspar is sometimes replaced by fluorite which occurs in minute, trellislike patterns along the cleavages of the feldspar. Hornblende, with X yellow, Y green, and Z bluish-green, with Z making an angle of 26° with c, is optically negative with a $2V$ of approximately 85° . It occurs as moderately elongated, anhedral crystals or crystal aggregates and is commonly associated with minor quantities of epidote, chlorite, biotite and magnetite which appears to be derived from the hornblende. Epidote is present as anhedral to subhedral crystals with a pleochroism of Y pale yellowish-green and X and Z colorless and a moderate birefringence of middle third-order interference colors. Biotite occurs as a few scattered plates with X yellow and Y and Z brown, magnetite as irregular masses to subhedral crystals, and chlorite as small shreds, plates, or semi-spherulitic aggregates that commonly pass into the hornblende. Apatite is present as small, euhedral to subhedral, hexagonal crystals of prismatic habit. They are common as inclusions in feldspar and hornblende, but only in minor quantities. Quartz and sphene are very minor constituents and each constitutes less than one per cent of the rock by volume. Quartz is present as a few, small anhedral crystals and sphene as minute, subhedral crystals with a pleochroism from brown to dark brown.

Inclusions of grayish-black, massive, coarsely-crystalline aggregates of hornblende with an average maximum-dimension

of twelve inches occur in the diorite. They have variable quantities of feldspar porphyroblasts which give rise to a complete transition between the inclusions and diorite. (Figs. 21, 22 and 23.)

Thin sections of the inclusions, when examined under the microscope, reveal a coarse to medium-grained aggregate of hornblende with variable and subordinate quantities of feldspar, chlorite, tremolite, sericite, iron ore and apatite. Hornblende is present as anhedral, elongate crystals in the matrix and as numerous inclusions in the porphyroblasts of feldspar. It is biaxial negative with a $2V$ of approximately 85° and has a pleochroism of X yellow, Y green and Z bluish-green with Z making an angle of 25° with c. It may have small patches of tremolite that are geometrically oriented on the hornblende to give it a mottled appearance. The tremolite, which is optically negative with Z making an angle of 14° with c, may or may not be present. Chlorite is also derived from hornblende and may be observed in variable amounts in all sections. Tremolite and chlorite are closely associated with the development of porphyroblasts of feldspar in the crystals of hornblende. Feldspar is present as subhedral to anhedral porphyroblasts with an average diameter of four millimeters. It has a composition of An_{37} to An_{42} and is frequently zoned with the cores being more calcic than the rims. They may be fresh or show some sericitization, and frequently they are replaced by minute quantities

PLATE NO. 21

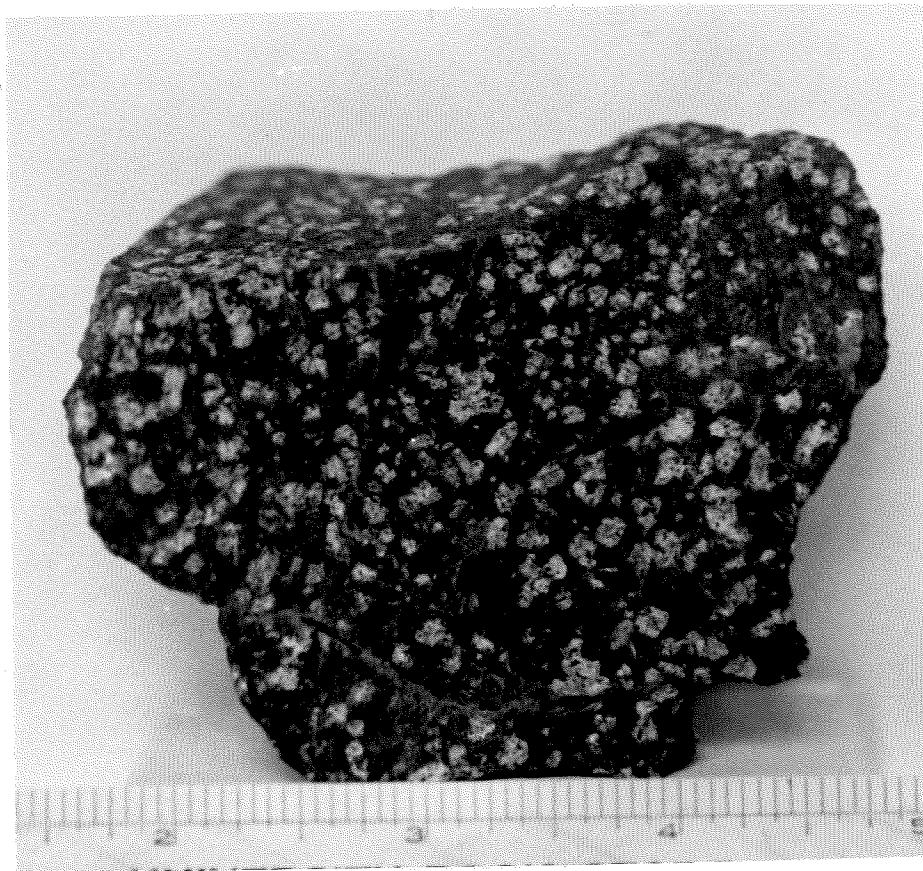


Fig. 21 - Photograph of a hand specimen from a skialith on the southwest slope of Klone Peak. Porphyroblasts of plagioclase are conspicuous. Diorite is the host rock of the skialith.

PLATE NO. 22

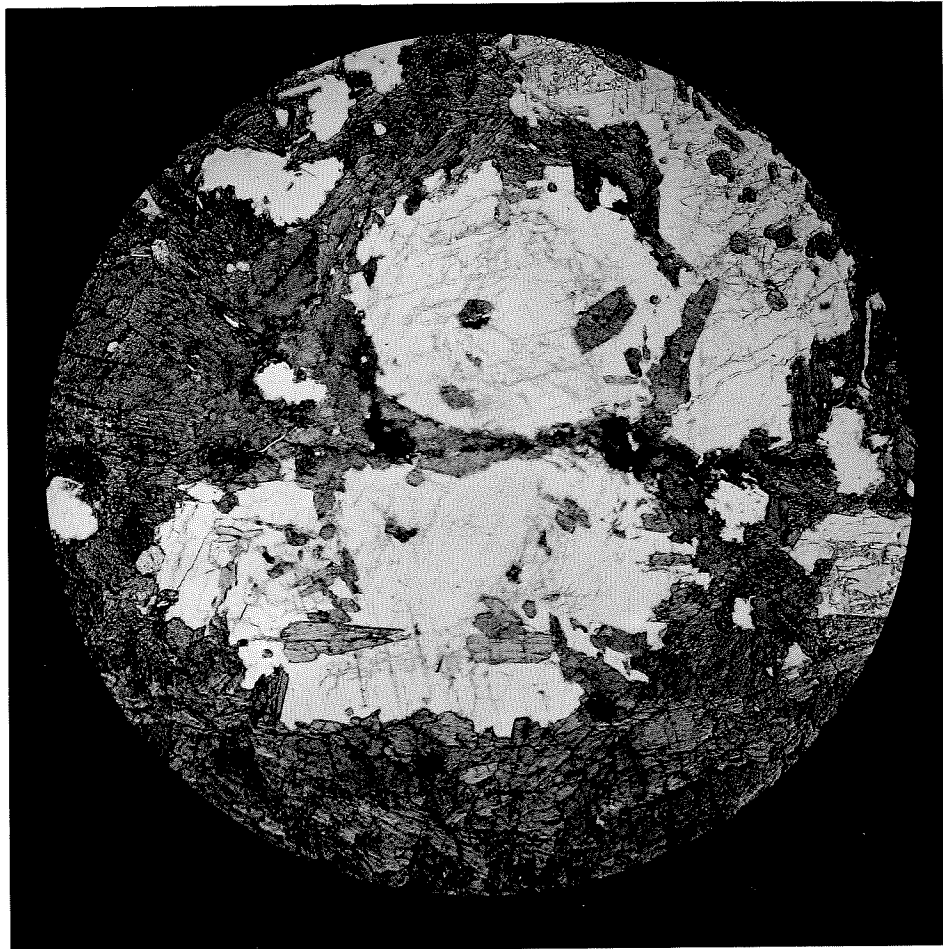


Fig. 22 - Photomicrograph of skialith in Fig. 21 showing porphyroblasts of feldspar (An₃₉). (Plain light; X16)

PLATE NO. 23

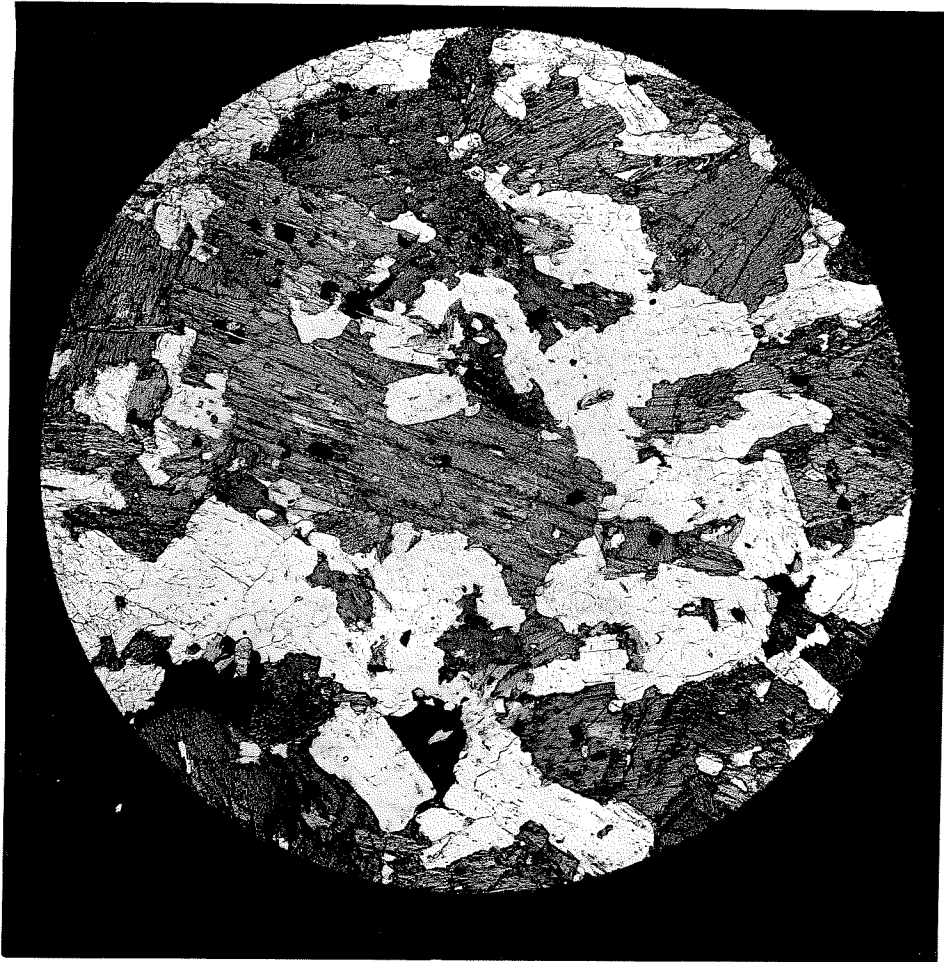


Fig. 23 - Photomicrograph of the host rock (diorite) of the skialith in Fig. 21 showing a more advanced stage of crystalloblastic development than illustrated in Fig. 22. Feldspar (An_{38}) and hornblende are the dominant minerals. (Plain light; X20)

of fluorite along the cleavages to form trellislike patterns. Inclusions of hornblende and chlorite are abundant with the former being more common. The iron ore is present as irregular masses of magnetite, and it is associated with the hornblende. Euhedral to subhedral crystals of apatite with prismatic form are a minor constituent of the rock.

Petrogenesis

The widespread distribution and character of the crystalline schists of the Metamorphic Complex strongly suggest that we are dealing with regionally metamorphosed and metasomatically migmatized and granitized sediments and basic igneous rocks. Let us first consider the rocks of the Swakane facies.

Swakane Facies. (Biotite-Muscovite-Quartz-Schist and Staurolite-Biotite-Quartz-Schist). The author interprets the biotite-muscovite-quartz-schist in the area southeast of Maverick Peak as being regionally-metamorphosed argillaceous and arenaceous sediments. He considers these rocks to be part of the same series of regionally-metamorphosed sediments that is represented on Nason Ridge as biotite-muscovite-quartz-schist and staurolite-biotite-quartz-schist, the latter being also present along Chiwaukum Creek. These crystalline schists are lower-medium-grade metamorphic rocks. The staurolite-biotite-quartz-schist represents a zone of slightly higher grade of metamorphism which is probably related to the origin of the Mt. Stuart granodiorite to the southwest and west of the area under

consideration.

(Amphibolite Schist). The amphibolite-schist could have been derived from basic igneous rocks (Waters, 1932) or sediments that were rich in lime and magnesia. Both types probably occur, but the common association of intercalated pods of marble with the amphibolite schists along the southern border of the quartz-diorite gneiss suggests to the author that they belong to the latter type.

(Marble). There is little to be said about the origin of the pods of marble. The marble is recrystallized limestone. The composition of the marbles described by the author, Waters (1932) and Chappell (1936) shows that the limestones were, for the most part, very pure. The pods were formed by intense deformation of the rocks.

(Talc-Carbonate-Rock). The talc-carbonate-rock is interpreted as being the end-product of a complex transformation of an ultrabasic igneous rock. The presence of relics of enstatite, along with antigorite, chlorite, and tremolite, suggests that the rock was originally an ultrabasic igneous rock, possibly related to the periodotites and serpentines to the southwest in the Mt. Stuart area (Smith, 1904). The mineral composition, their relative order of formation, and textures suggest that the transformation took place in at least two stages. The first stage was the formation of tremolite, chlorite and antigorite from the pyroxenes (enstatite and calcium

bearing pyroxenes) and olivine by regional metamorphism. The second stage was the alteration and replacement of tremolite and antigorite to talc and dolomite by the introduction of carbon dioxide. This is a low temperature process and took place after regional metamorphism. The carbon dioxide could have and probably did come from the atmosphere.

Part or all of the calcium necessary to form the tremolite might be interpreted by some as being produced by calcium-metasomatism. Unfortunately, lack of outcrops of adjacent country rock makes it impossible to prove or disprove such an hypothesis.

(Biotite-Gneiss). The biotite-gneiss is considered to be a permeation gneiss produced by metasomatic metamorphism. This interpretation is supported by both field and petrologic features. Most of the features have been fully described in previous sections, but the more salient ones will receive further mention here. (1) The biotite-gneiss is transitional with the associated crystalline schists - biotite-muscovite-quartz-schist, amphibolite-schist, and granodiorite-gneiss (Waters, 1930). (2) The foliation of the biotite-gneiss and associated crystalline schists have a common attitude. (3) The schistaliths of country rock have an undisturbed orientation. (4) The high quartz and inferred silica content of the biotite-gneiss would not be compatible with a rock of magmatic origin. (5) The high feldspar content would be difficult to explain in metamorphosed

sediments without considerable metasomatism. (6) The biotite-gneiss appears to have a common history with the granitic rocks of the Chelan facies with a sodium enrichment followed by a potassium enrichment. This relationship and the nature of the metasomatism will be discussed in a later section.

(Pegmatites). The pegmatites probably have a related history to the permeation gneiss described above. A replacement origin is suggested by the presence of undisturbed relics of country rock within the pegmatites. This hypothesis is further supported by transitional contacts between the pegmatites and country rock with an increase in the sodium content of the feldspars as the central portion of the sodic-oligoclase pegmatites are approached. This interpretation (replacement origin) is not new but was suggested by Chappell (1936) for the pegmatites in the Swakane gneiss in Wenatchee quadrangle.

Chelan Facies. At the junction of Mad and Jimmy Creeks the amphibolite-schist grades into quartz-diorite-gneiss of the Chelan facies. Is the quartz-diorite-gneiss of magmatic origin, or has it been formed by granitization? Magmatic origin implies that the rock was formed by the consolidation of a magma which Grout (1932) defines as ". . . a natural fluid in or on the earth, generally very hot, made up largely of a mutual solution of silicates, with some oxides and sulphides, etc.; it nearly always contains also water and other gases held in solution by pressure, but the heat is the main factor of its

liquidity. So far as known, no magma is solid - not even a weak gelatinous solid." On the other hand, Read (1948) defines granitization as ". . . the process by which solid rocks are converted to rocks of granitic character without passing through a magmatic stage." Therefore, our first problem of origin is to determine if the rocks passed through a fluid state. This is a problem of structure and petrology that can best be illustrated from field relationships and petrography respectively.

The field relationships and petrography have been described in the foregoing sections, but some pertinent observations will be stated again. (1) The foliation of the crystalline schists of the Metamorphic Complex have a common attitude which conforms to a regional structure. (2) The quartz-diorite-gneiss, which constitutes 93 per cent of the area of the Chelan facies, has inclusions of country rock (amphibolite). The foliation of the inclusions and enclosing gneiss has a common attitude which conforms to the regional structure (Plate No. 47). The distribution and size of many of the inclusions would eliminate any possibility of the inclusions being projections of the country rock into the gneiss. (3) The contact between the quartz-diorite-gneiss and amphibolite schist of the Swakane facies is gradational¹ with every degree of transition

1 The gradational contact zone may exceed several hundred feet in width.

from one rock type into the other. Although the contact zone is nearly vertical and transverse to the foliation, the attitude of the foliation does not change as it passes from the schist into the gneiss (Plate No. 47). (4) Epidote is present as a primary constituent (Fig. 24) of the quartz-diorite-gneiss as well as a late alteration product. (5) The quartz-diorite-gneiss and amphibolite have a related mineral assemblage. (6) The porphyroblasts of feldspar in the amphibolite are like those in the adjacent "granitic" rock.

The author interprets the field relationships to mean that transformation took place in a solid state. The preservation of the attitudes of the inclusions (skialiths) can best be explained as relics of country rock that have undergone transformation in the solid state. The structural continuity that exists between the "granitic" and "non-granitic" rocks also suggests this hypothesis. This interpretation is supported by the petrologic evidence. The related mineral assemblages in the amphibolite-schist and quartz-diorite-gneiss and the porphyroblasts of feldspar in the amphibolite-schist suggest a common environment. The presence of primary epidote in the quartz-diorite-gneiss is not compatible with a magmatic hypothesis.

(Diorite Subfacies). The diorite is considered to be granitized basic rocks whose nature is suggested by the basic inclusions of amphibolite that are always associated with the diorite. Every degree of development of feldspar porphyro-

PLATE NO. 24

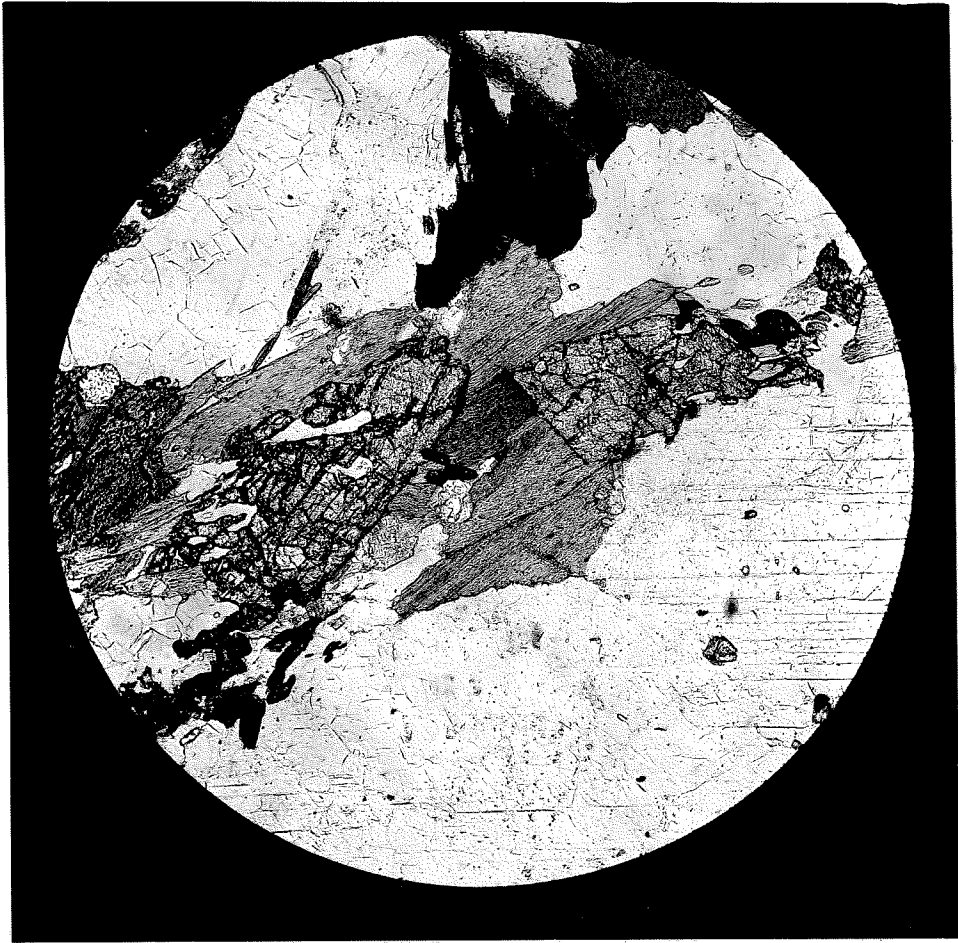


Fig. 24 - Photomicrograph of quartz-diorite-gneiss showing epidote at a normal constituent of the rock.

blasts may be seen thereby giving a complete transition between the inclusions and diorite (Figs. 21, 22 and 23). An inferred gradation between diorite and quartz-diorite-gneiss gives further support to the hypothesis.

(Granodiorite-Gneiss Subfacies). The replacement origin of the granodiorite-gneiss is clearly illustrated in the field, in thin sections, and in stained polished-sections.¹ In the field, a complete gradation may be observed between the granodiorite-gneiss and quartz-diorite-gneiss with the preservation of a common foliation or structure. In thin sections and stained polished-sections, the replacement of plagioclase by microcline and orthoclase is clearly shown.

Nature of Metasomatism

No chemical analysis of the rocks was made, therefore quantitative data of the chemical composition of the rocks are lacking. Without such data any discussion on the chemical changes that took place during metasomatism is often little more than qualitative. It is in this light that the author offers the following suggestion regarding the chemical nature of the metasomatic changes that have taken place.

In the transformation of amphibolite-schist to quartz-diorite-gneiss, the metasomatic formation of sodic plagioclase

1 The sodium cobalt nitrite method of Gabriel and Cox (1929) was used for identifying potash feldspars. The potash feldspars become intensely yellow, the quartz remains unchanged, and the plagioclase becomes white and opaque.

with the production of biotite and epidote is the dominant process. This change requires an enrichment of sodium and strongly implies an enrichment in silica which is shown by the presence of approximately 15 per cent quartz and a more sodic plagioclase in the quartz-diorite-gneiss. Part of the calcium was taken up by epidote, but may have migrated to the migmatite front to furnish the calcium necessary for the permeation gneisses. The percentage of sphene remains rather constant, and appears to remain stable during the process of transformation. The change in mineral composition also suggests a release of iron and magnesium in the transformation of amphibolite-schist to quartz-diorite-gneiss. A small increase in magnetite in the quartz-diorite-gneiss accounts for at least part of the iron, but some may have gone elsewhere.

The origin of the diorite is intimately associated with the origin of the quartz-diorite-gneiss. Here again, the dominant process was an enrichment in sodium and silica which gave rise to the metasomatic formation of plagioclase with the development of some biotite. An excess in silica is shown by the presence of quartz which increases in quantity as the diorite grades into quartz-diorite-gneiss. The change in mineral composition in the transformation of amphibolite into diorite suggests a release of calcium, iron and magnesium. Some of the calcium may have been precipitated in the permeation gneisses, and part of the iron may be accounted for in the magnetite in

the diorite.

A late introduction of potash and silica is shown in the granodiorite-gneiss by the replacement of oligoclase by microcline and orthoclase and by an increase in the quartz content of the rock. This reaction was accompanied with the formation of muscovite and the disappearance of hornblende and a marked decrease in biotite. Some calcium went into the formation of epidote, but some may have been released to go elsewhere. The change in mineral composition also implies a release of iron and magnesium.

We have now established two phases of metasomatism - a predominant sodium metasomatism followed by a predominant potash metasomatism - in the rocks of the Chelan facies. How does this relationship compare with the permeation gneisses and pegmatites of the Swakane facies? Let us first consider the permeation gneisses.

The transformation of a biotite-muscovite-quartz-schist to the feldspar-rich (calcic-oligoclase) permeation gneiss would require an enrichment in sodium and some calcium, the calcium, as suggested above, being the excess calcium from the transformation of amphibolites to quartz-diorite-gneiss. The schist may have had ample quartz to furnish the necessary silica, therefore the supply of silica is no problem. The replacement of calcic-oligoclase by orthoclase and microcline bears witness to a late potash metasomatism in the permeation gneiss.

The pegmatites are considered to represent concentrations of sodium and potassium enrichment. The sodic-oligoclase pegmatites are interpreted as being formed by sodium metasomatism, and the potash-feldspar pegmatites are interpreted as being formed by potash metasomatism. Unfortunately, the two types of pegmatites were not observed in contact with each other, but it seems reasonable to the author to consider that they were produced by the same emanations (sodium enrichment followed by potassium enrichment) that produced the permeation gneisses and rocks of the Chelan facies. This evidence is not conclusive, and further field work should be done to try to establish a positive time relationship between the two types of pegmatites.

Time of Metasomatism

The beginning of metasomatism may have been synkinematic which is suggested by the conspicuous gneissose-structure in the granitic gneisses. However, the gneissose structure is an inherited, relic structure which is shown by the textures produced by post-kinematic metasomatism and crystallization. The aligned aggregates of unorientated plates of biotite which penetrate the crystals of feldspar bear witness to post-kinematic crystallization. Further evidence of post-kinematic crystallization is illustrated by irregular skialiths with thin and undisturbed extensions and by unrotated porphyroblasts of feldspar in the skialiths and in the country rock at the con-

tact. In the non-granitized mica schists, the presence of plates of mica orientated across the foliation testifies that crystallization continued under static conditions.

Age and Correlation

The age of the regionally metamorphosed, migmatized, and granitized sediments and basic igneous rocks is not known. They may range from Pre-Cambrian to Middle Mesozoic in age. Fossils of Permian age have recently been reported by Danner (1950) from limestones in Skykomish quadrangle; fossils of Ordovician age had previously been reported by Warren S. Smith from rocks in the same area. Rocks of equivalent age may or may not be present in northeastern Chiwaukum quadrangle.

The date of regional metamorphism and granitization is not definitely known, but it is usually assigned to late Jurassic (Nevadian disturbance). Whatever the exact date, the surface was reduced to a broad lowland before the deposition of the Swauk sediments in Paleocene and possibly uppermost Cretaceous time.

The rocks of the Swakane facies are correlated with the Swakane gneiss of Chelan quadrangle (Waters, 1930) and the Chiwaukum schist of southeastern Chiwaukum quadrangle (Page, 1939). Evidence for these correlations have been fully discussed in previous sections.

The rocks of the Chelan facies are correlated with the quartz-diorite-gneiss, granodiorite-gneiss, and Chelan grano-

diorite of Chelan quadrangle (Waters, 1930). This correlation is based on reconnaissance field work of the author and Waters (1930) who traced the Chelan batholith along the Entiat River to its headwaters. However, it should be noted that the Chelan granodiorite is described by Waters (1930) as having augite as a common accessory mineral. This mineral was not observed in the rocks of the Chelan facies or in the few samples of Chelan granodiorite collected by the author in Chelan quadrangle along the Entiat and Columbia Rivers. Further work needs to be done on this granitic mass.

Pre-Swauk Intrusives

The pre-Swauk dikes form a transitional complex which has been divided by the author into spessartites, granophyric-granodiorite-porphyrtes, and granophyres, named in the order of their decreasing abundance. The spessartites have been further divided into mela-spessartites, meso-spessartites, and a porphyritic variety of meso-spessartites. The individual dikes have a uniform composition, but as a group they show a transition from spessartites to granophyres.

In the area under consideration, the dikes are restricted to the Entiat Mountains where they cut the rocks of the Metamorphic Complex. They are apparently more abundant north of the contact between the rocks of the Chelan and Swakane facies, but this difference may be due to sparse rock exposures

south of the contact.

In the southern half of Chelan quadrangle, Waters (1927, 1930) gives an excellent description of a transitional "lamprophyre-granophyre series" of dikes common in that area, notably at Corbaley Canyon. Further mention of lamprophyre dikes is made by Chappell (1936) in northeastern Wenatchee quadrangle.

The dikes cut the rocks of the Metamorphic Complex with a nearly vertical attitude. The spessartite dikes, which are the most common in the area, range in thickness from a few inches to fifty feet, the six granophyric-granodiorite-porphyr dikes from a few feet to 125 feet, and the one granophyre dike had a thickness of ten feet. The dikes usually have chilled or fine-grained selvages and sharp contacts with the country rock. Composite dikes are not common, but spessartite dikes may consist of two or more rock types of slightly different character with chilled contacts between them. For the most part, the more acidic dikes are relatively later than the basic dikes as found by Waters (1927, 1930) in the Chelan quadrangle, but two exceptions were observed with spessartites cutting granodiorite-porphyr.

Mela-Spessartite

In hand specimen, the mela-spessartites have a dark gray, aphanitic groundmass with euhedral, prismatic phenocrysts of hornblende. The phenocrysts have a maximum length of one

centimeter and have a random orientation. They constitute about 15 per cent of the rock by volume.

In thin sections (Fig. 25) when examined under the microscope, the rock is holocrystalline with a fine-grained matrix - dominantly of feldspar, hornblende, and chlorite with minor quantities of sphene, iron ore, apatite, carbonate, and quartz - with abundant phenocrysts of hornblende. Hornblende with X yellow, Y brown and Z dark brown with Z making an angle of 15° with c is an abundant mineral in the matrix as small, euhedral crystals and as euhedral phenocrysts with a maximum length of five millimeters. It is frequently altered to chlorite and occasionally to carbonate and minute quantities of quartz. Inclusions of sphene, magnetite and apatite may be observed with the former being the more common. Feldspar, with a composition of An_{28} , is the most abundant mineral of the matrix. It fills the interstices between the crystals of hornblende which gives rise to anhedral and subhedral crystals with numerous inclusions (poikilitic) of hornblende and lesser quantities of subhedral to euhedral crystals of sphene and magnetite and minor amounts of small, euhedral, prismatic crystals of apatite. It is usually fresh but may be altered to carbonate and some quartz.

PLATE NO. 25

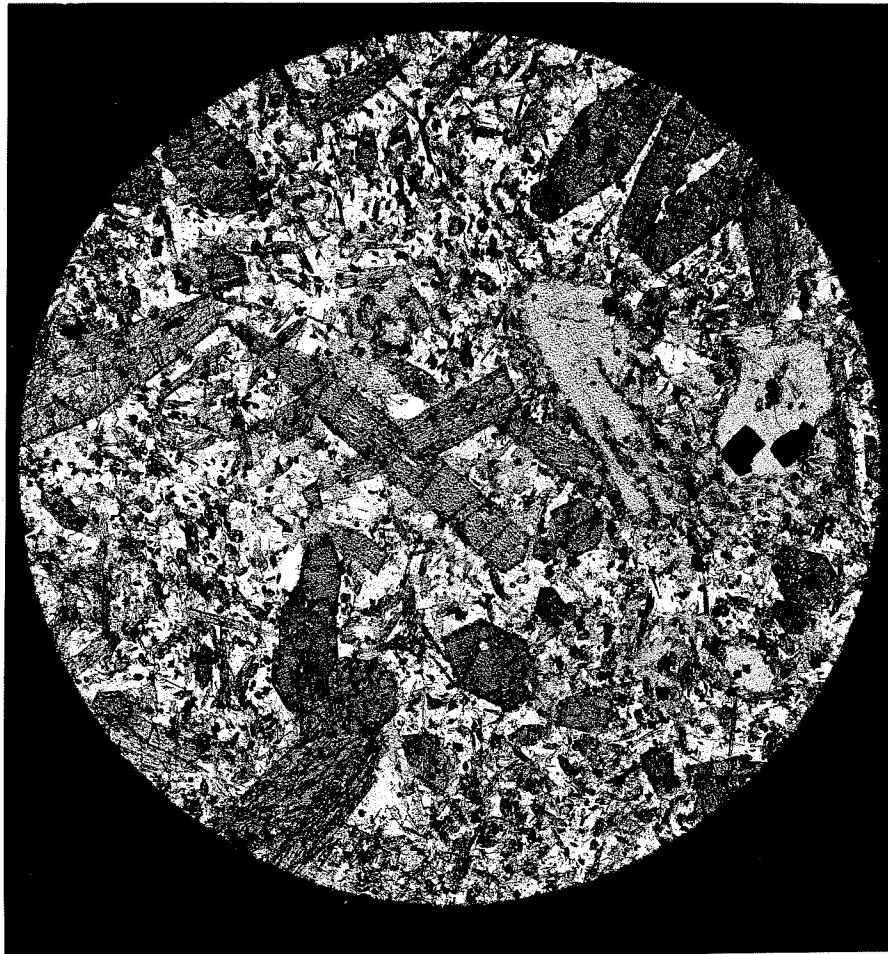


Fig. 25 - Photomicrograph of mela-spessartite illustrating hornblende phenocrysts in a matrix consisting dominantly of plagioclase and hornblende. (Plain light; X20)

Meso-Spessartite

Megascopically, the meso-spessartites are gray, medium-grained rocks with abundant, euhedral, prismatic crystals of grayish-black hornblende separated by grayish-white aggregates of feldspar. The crystals of hornblende have a random orientation and a maximum length of seven millimeters. Small crystals of pyrite are occasionally observed.

When examined under the microscope, thin sections (Fig. 26) of the meso-spessartites reveal a holocrystalline, medium-grained, porphyritic aggregate with phenocrysts of euhedral to subhedral crystals of hornblende in a matrix dominantly of euhedral to subhedral, prismatic crystals of plagioclase with subordinate quantities of chlorite, hornblende, magnetite, sphene, apatite, and micrographic intergrowths of quartz and orthoclase. Most of the hornblende, with X yellow, Y brown and Z dark brown with Z making an angle of 16° with c, is present as phenocrysts with a maximum length of seven millimeters, but a few small crystals constitute part of the matrix. It is commonly altered to chlorite and magnetite and occasionally to carbonate and quartz. Inclusions of euhedral crystals of magnetite and apatite are sometimes observed. The plagioclase is often zoned with cores of andesine and mantles of oligoclase. It is usually turbid and may be altered to epidote, carbonate and quartz. Inclusions of euhedral to subhedral magnetite and euhedral prismatic crystals of apatite are frequently observed.

PLATE NO. 26

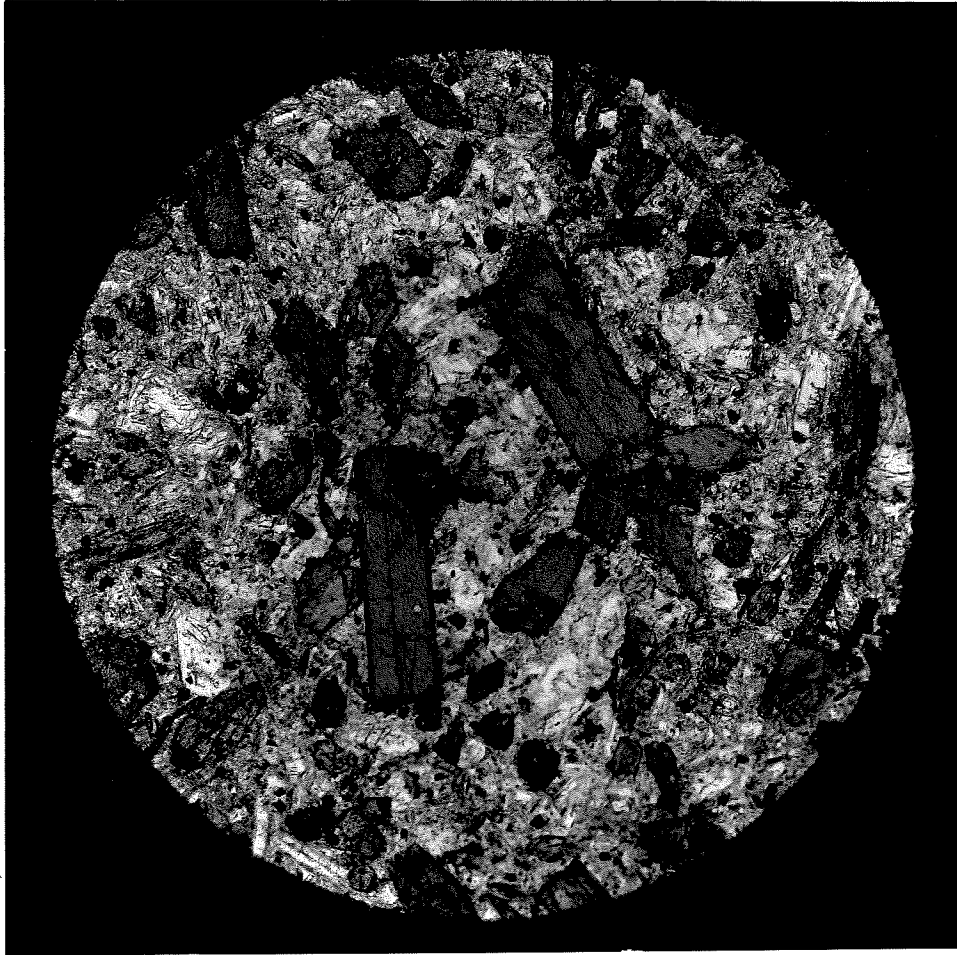


Fig. 26 - Photomicrograph of meso-spessartite showing hornblende phenocrysts in a matrix consisting dominantly of plagioclase. (Plain light; X20)

The primary quartz is interstitial with plagioclase and hornblende. It is commonly intergrown with orthoclase to form micrographic textures. Irregular masses of secondary pyrite are present in small quantities. They are sometimes altered to limonite. Augite is sometimes present as euhedral to subhedral phenocrysts. It frequently passes into brown hornblende which has a parallel position on the augite.

Porphyritic Variety of Meso-Spessartite

In hand specimen, the porphyritic spessartite has a gray, aphanitic groundmass with phenocrysts of white feldspar, colorless quartz, and grayish-black hornblende. Feldspar is the most conspicuous phenocryst. It is of anhedral habit and has a maximum diameter of ten millimeters. The hornblende is euhedral and prismatic in habit with a maximum length of four millimeters. Quartz is a minor constituent and is anhedral with a maximum diameter of four millimeters.

When thin sections are examined microscopically, the rock is seen to consist of phenocrysts (Figs. 27 and 28) of hornblende, plagioclase and quartz in a fine-grained, holocrystalline matrix (Fig. 28) of plagioclase and subordinate hornblende with minor quantities of magnetite, sphene, apatite, and interstitial, micrographic quartz that is intergrown with orthoclase. The plagioclase phenocrysts are usually in clusters which gives rise to glomeroporphyritic textures. They have a composition of An_{42} and are often zoned with cores of

PLATE NO. 27

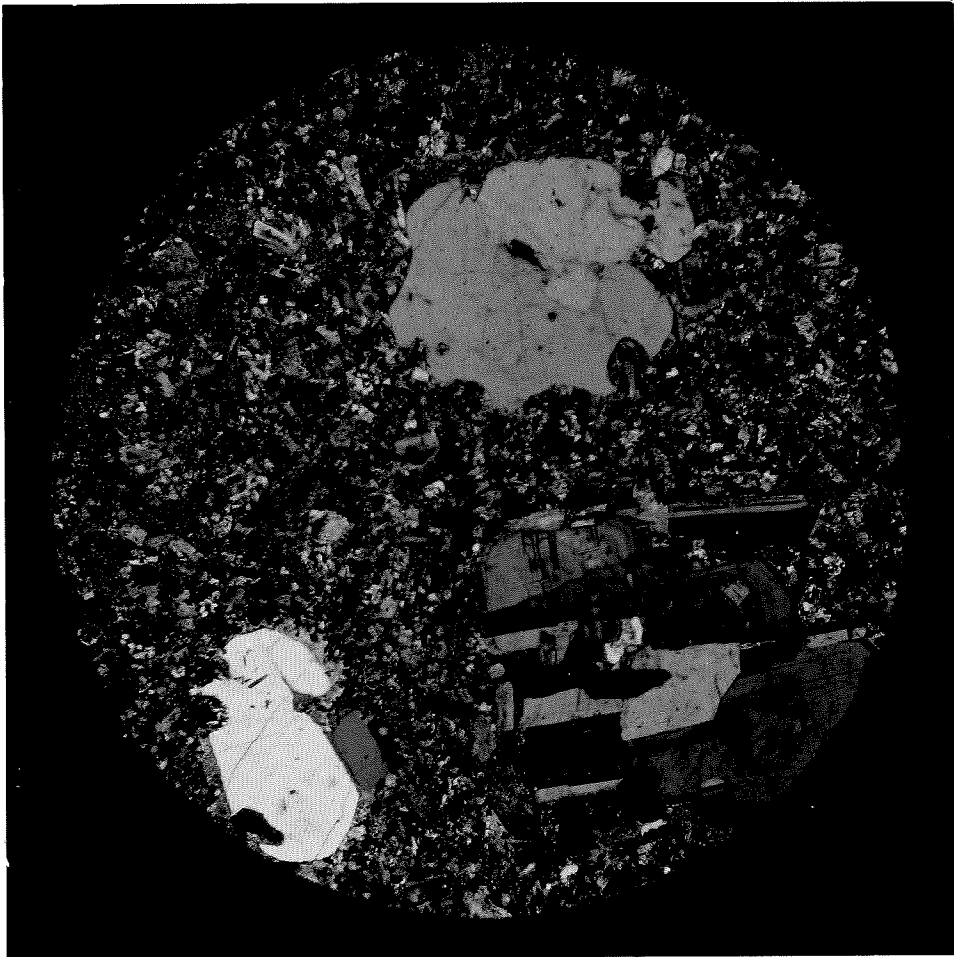


Fig. 27 - Photomicrograph of a porphyritic variety of meso-spessartite with conspicuous phenocrysts of plagioclase and quartz, the latter mineral being subordinate. (Under crossed nicols; X20)

PLATE NO. 28

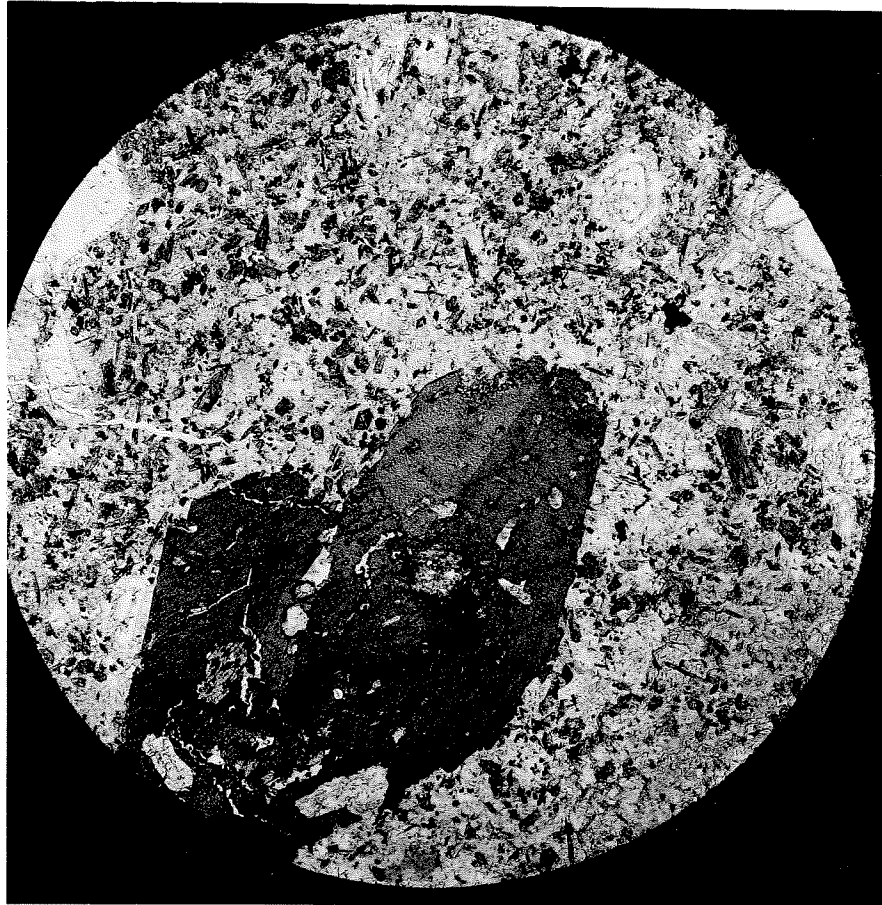


Fig. 28 - Photomicrograph (Plain light; X20) of the section illustrated in Fig. 27 showing hornblende as a phenocryst and as a common constituent of the matrix. The micrographic intergrowth between quartz and orthoclase is rather difficult to recognize.

more calcic composition. They may have inclusions of apatite and biotite with X yellow and Y and Z dark brown to opaque. They are usually corroded. The phenocrysts of hornblende, with X yellow, Y brown and Z dark brown with Z making an angle of 15° with c, are euhedral and prismatic with a maximum length of three millimeters. They are frequently altered to chlorite and may have inclusions of apatite, magnetite and sphene. The quartz phenocrysts have a maximum diameter of three millimeters. They are corroded with the production of embayments and frequently have reaction rims of hornblende. The plagioclase of the matrix has a composition of An_{32} , and is frequently zoned with more calcic cores. It is euhedral to anhedral in habit with simple contacts. It is usually turbid, and inclusions of minute, euhedral to anhedral crystals of magnetite and hornblende with X yellow, Y brown and Z dark brown are common. Quartz is interstitial and is frequently intergrown with orthoclase to give micrographic textures.

Granophyric-Granodiorite-Porphyry

Megascopically, the granophyric-granodiorite-porphyry is a light gray, medium-grained rock that consists dominantly of feldspar with subordinate quantities of quartz and biotite. The rock is often nearly wholly megacrystalline, but a gray, aphanitic matrix is sometimes conspicuous and may constitute as high as 40 per cent of the rock by volume.

When thin sections (Fig. 29) of the rock are studied under the microscope, a holocrystalline, porphyritic aggregate may be seen with phenocrysts of plagioclase, biotite and quartz with the former being dominant, in a matrix that is usually granophyric (Fig. 30) but may be micro-granular. The granophyric intergrowths are commonly micropegmatitic with intergrown quartz and orthoclase. The phenocrysts of plagioclase are often in clusters (glomeroporphyritic) with a maximum diameter of five millimeters. They have a composition of An_{36} , and may be zoned with cores of more calcic composition. They vary in form from subhedral to euhedral crystals. Quartz phenocrysts are a subordinate constituent and constitute about 10 per cent of the rock by volume. They are usually single anhedral crystals with a maximum diameter of three millimeters, but they may be glomeroporphyritic. Euhedral to subhedral phenocrysts of biotite with X yellow and Y and Z dark brown to opaque are always present. They may be altered, in part, to chlorite.

Granophyre

In hand specimen, the granophyre is pale gray with a fine-grained matrix of feldspar and subordinate quartz with small phenocrysts of euhedral to subhedral feldspar and anhedral quartz. The phenocrysts have a maximum diameter of three millimeters and constitute about 25 per cent of the rock by volume. Shreds of biotite are present, but they are a very minor con-

PLATE NO. 29

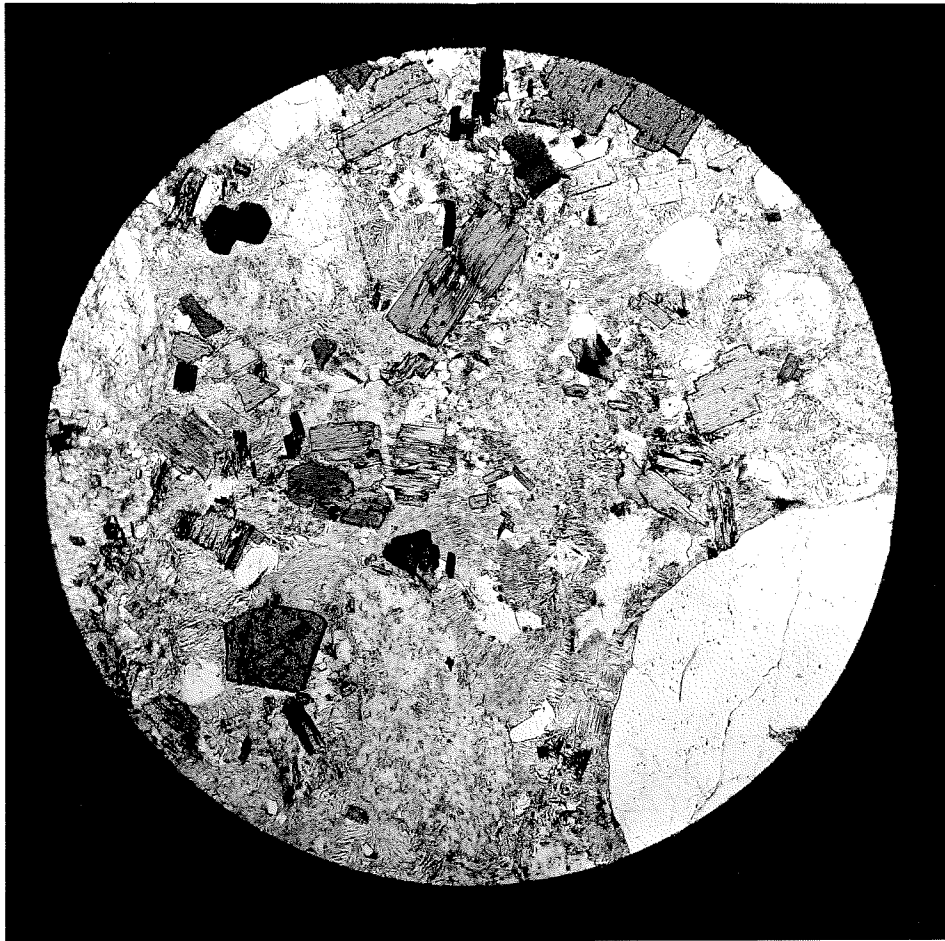


Fig. 29 - Photomicrograph of granophyric granodiorite porphyry. The phenocrysts - plagioclase, biotite and quartz - are in a granophyric matrix which is best illustrated in Fig. 30. (Plain light; X20)

PLATE NO. 30

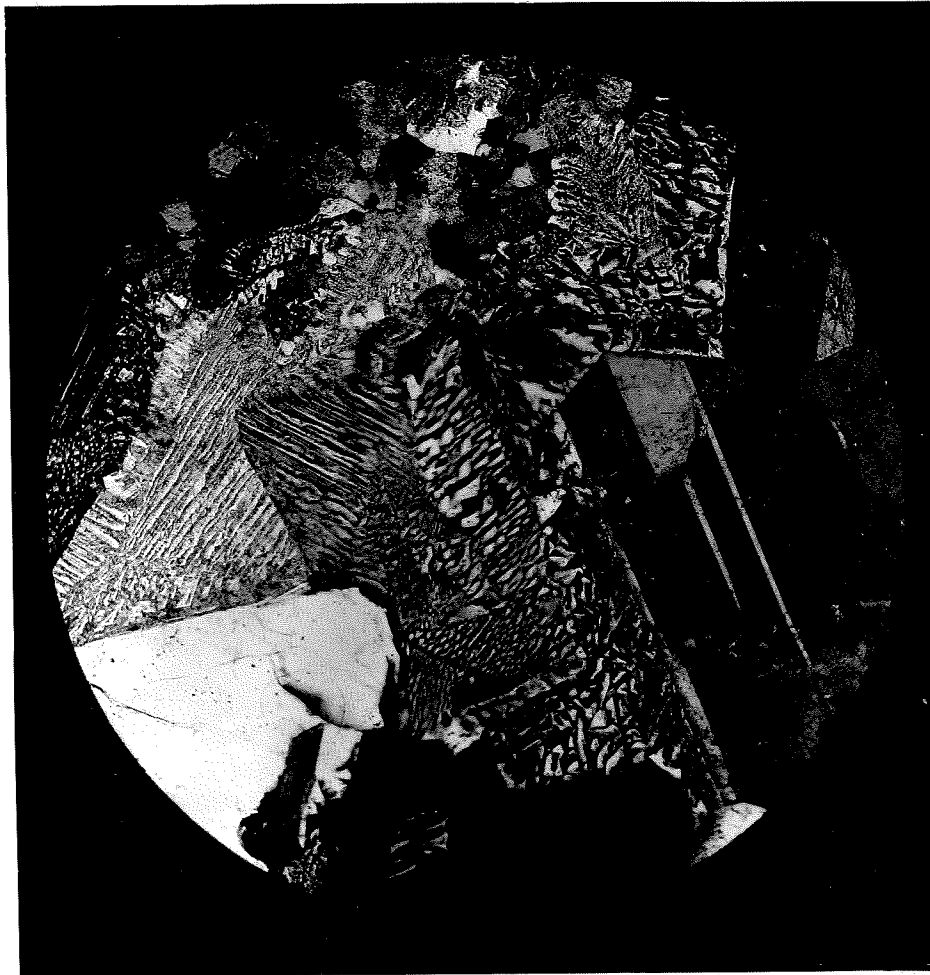


Fig. 30 - Photomicrograph of granophyric granodiorite porphyry illustrating granophyric matrix. The phenocrysts are plagioclase and quartz. (Under crossed nicols; X54)

stituent of the rock.

Thin sections (Fig. 31) of the granophyre, when examined microscopically, reveal a granophyric matrix with euhedral to anhedral phenocrysts of quartz, orthoclase and plagioclase with maximum diameters of three millimeters. The matrix constitutes about 75 per cent of the rock by volume and consists of intergrown quartz and orthoclase with plumose and micropegmatitic forms, the former being more common. The contacts between the granophyric matrix and phenocrysts of feldspar are usually sharp, but some reaction borders may be observed. The plagioclase has a composition of An_{34} and often shows sericitization. Biotite, with X yellowish-green and Y and Z dark green, is present as shreds that cut across the granophyric intergrowths. It is a very minor constituent of the rock and is frequently altered to chlorite.

Petrogenesis

The author interprets the dikes as being formed from a common parent magma that was injected at different stages of differentiation. Evidence for a magmatic origin lies in the presence of chilled selvages, sharp contacts with the country rock, porphyritic textures with euhedral phenocrysts and two ages of plagioclase. Magmatic differentiation of a common parent magma is suggested by the intimately related mineral composition of the dikes. The mineral composition varies mostly in the relative abundance of the constituent minerals and not in

PLATE NO. 31

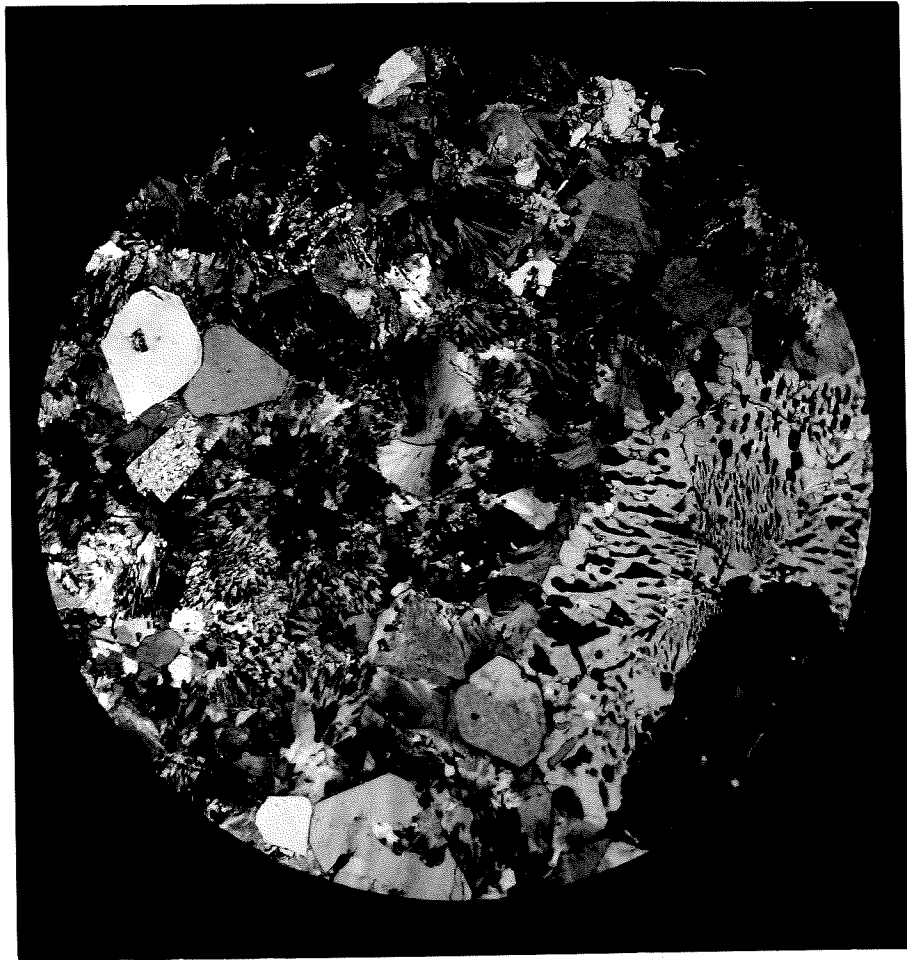


Fig. 31 - Photomicrograph of granophyre showing spherulitic and micrographic intergrowth between potash feldspar and quartz. (Under crossed nicols; X20)

the kind of minerals present. The injection of magma at different stages of differentiation is illustrated by the difference in composition between the individual dikes. These dikes, as a group, show a complete transition between melaspessartites and granophyres with a progressive increase in the quantity of silica and potash from the former to the latter (Figs. 25, 26, 27, 28, 29, 30 and 31).

Age

The dikes are post-Metamorphic Complex and pre-Swauk in age. The dikes cut the rocks of the Metamorphic Complex, but they have never been observed or reported cutting the rocks of the Swauk formation.

Swauk Formation

Type Locality

The Swauk formation receives its name from Swauk Creek in the northern part of the Mt. Stuart quadrangle where it was first mapped and described by George Otis Smith (1904). Smith described the Swauk formation as consisting of sandstone, shale and conglomerate which are bedded and interstratified. The sandstone usually has the general character of a gray, biotite-bearing arkose, but in the vicinity of Mission Creek and its tributaries, the sandstone becomes more quartzose. The shale is commonly black and carbonaceous, and it frequently contains

abundant and well-preserved fossil leaves. The conglomerate is local in occurrence and is usually confined to the lower portion of the formation. The basal beds¹ are commonly conglomerate, but they may be sandstone or shale. Their composition is usually related to the underlying rocks of the basement complex.

Smith states: "No general section or succession can be given for the formation, since it varies widely in different parts of the area. In some places it is probable that the Swauk formation aggregates over 5000 feet, while in others 3500 feet may be a more accurate estimate. The original thickness of this sedimentary formation cannot be definitely determined, since there was erosion of portions of the uppermost beds soon after deposition."

The lower limit of the Swauk formation is defined by a major unconformity. Basal members of the Swauk formation rest upon diverse rock types of the basement complex. The Swauk formation is limited above by the overlying Teanaway basalt which rests unconformably on truncated strata of the Swauk formation.

1 R. L. Lupper (1944) refers to these beds, at least in part, as being "discontinuous deposits of mudstones, sandstones and conglomerates derived from the peridotite and older rocks and containing various amounts of iron oxide. These lenses are exposed at a number of places ... in a linear distance of 22 miles from upper Peshastin Creek near Blewett Pass westward to and beyond the Cle Elum River. Only in a few localities do they exceed a thickness of 25 feet and the maximum observed thickness is about 450 feet. Nevertheless they constitute a sharply defined stratigraphic unit here called the Cle Elum formation."

The strata of the Swauk formation have been warped into narrow folds that usually have northwest-southeast trending axes. The folds are usually open with limbs inclined at 25°, but steeply inclined to vertical strata have been noted in a few localities.

Regional Distribution

The Swauk formation forms an east-west belt across the northern part of Mt. Stuart quadrangle that extends eastward across Wenatchee quadrangle (Chappell, 1936) and westward into the northeastern corner of the Snoqualmie quadrangle (George Otis Smith and F. C. Calkins, 1906). From Snoqualmie quadrangle, it extends northwestward across Skykomish quadrangle where it has been mapped and described by W. S. Smith (1915, 1916), Charles E. Weaver (1912), and J. E. Spurr (1900, 1901). From Wenatchee quadrangle, it extends northwestward across Chiwaukum quadrangle and the southwestern corner of Chelan quadrangle where it has been studied and mapped by A. C. Waters (1930), Ben Fage (1939), and the author.¹ Part of the arkosic sandstones that occur at intervals on the eastern (Weaver, 1937) and western slopes of the Cascade Mountains northward to the international boundary may be equivalent, at least in part, to the Swauk formation.

¹ The northwestern portion of this belt is included in the area under consideration in this report.

Age and Correlation

The age of the Swauk formation was first determined by F. H. Knowlton from the collection of fossil leaves made by George Otis Smith (1904) from the type locality in the vicinity of Liberty in the Mt. Stuart quadrangle. Twenty-five species were recognized, all of which were new. They are from the following genera:

Lygodium

Sabal

Myrica

Comptonia

Populus

Quercus

Ficus

Cinnamomum

Prunus

Diospyros

Lizyphus

Celastrinites

Phyllites

A form or variety of only one previously known species, Ficus planicostata, was found in the collection. It is a common species in the Denver and Laramie formations of uppermost Cretaceous age. Other species have a rather close resemblance

to certain species of the Laramie, Denver and Fort Union formations. On this evidence, P. H. Knowlton regarded the age of the Swauk formation as early Eocene. However, the Fort Union formation is now recognized as being Paleocene in age (R. C. Moore, 1949), which slightly modifies the above interpretation.

The collection of fossil leaves made by Warren S. Smith (1916) from the Swauk formation of Skykomish quadrangle were examined by Caroline A. Duror who identified and described the following fifteen genera and nineteen species:

Genus Asplenium

Asplenium magnum var. intermedium var. novum
(Duror).

Genus Pteris

Pteris pennaeformis (Heer)

Genus Sabal

Sabal powelli (Newb.)

Genus Glyptostrobus

Glyptostrobus ungeri (Heer)

Genus Taxodium

Taxodium distichum Miocenum (Heer)

Genus Sequoia

Sequoia nordenskioldi (Heer)

Genus Ficus

Ficus ungeri (Lesq.)

Ficus Sp. (Knowlton)

- Genus Hicoria
Hicoria (Carya) antiquorum
(Newb., Knowlton)
- Genus Juglans
Juglans acuminata (Heer)
- Genus Laurus
Laurus cascadia N.Sp.
- Genus Magnolia
Magnolia nordenskioldi (Heer)
- Genus Populus
Populus amblyrhynca (Ward)
Populus cuneata (Newb.)
Populus zaddachi (Heer)
Populus artica (Heer)
- Genus Protoficus (Saporta)
Protificus fossi N.Sp.
- Genus Pterospermites
Pterospermites whitei (Ward)
- Genus Sapindus
Sapindus obtusifolius (Lesq.)

Two of the species were new, but the other seventeen species had been reported from the Fort Union formation. On this evidence Miss Duror considered the Swauk formation to be Fort Union in age.

Of the above genera, Juglans, Populus, Laurus, Ficus and Sabal had been reported by F. H. Knowlton from a collection of fossil leaves made by Bailey Willis (1899) from the Puget Group in the Carbon River area of western Washington. On this evidence, Warren S. Smith correlated the Swauk formation with the lower Puget Group (Carbonado) of western Washington.

Specimens of fossil leaves were collected by Waters (1930) from a locality two and one-half miles southeast of Leavenworth on the west bank of the Wenatchee River and from a second locality one-half mile north of Mission. The collection was submitted to R. W. Brown who recognized the following nine genera:

Sabal

Celastrus

Comptonia

Zizyphus

Ficus

Populus

Laurus

Magnolia

Pterospermites

With the exception of genus Celastrus, the above genera had been reported by F. H. Knowlton and Miss Duror from the Mt. Stuart and Skykomish quadrangles respectively.

At the time of Waters' (1930) work, some paleontologists had assigned the Fort Union along with the Denver and Laramie formations to upper Cretaceous in age. It was, in part, on this evidence that Waters considered the Swauk formation to be of Cretaceous age.

Chappell (1936) collected specimens of fossil leaves from the Swauk formation in Wenatchee quadrangle. They were submitted to R. S. LaMotte, who made subsequent collections from the Swauk formation in Wenatchee, Chiwaukum and Mt. Stuart quadrangles for identification and age determination. From the combined collections, LaMotte recognized the following forms:

Genus Schizaeaceae

Anemia occidentalis (Knowlton)

Lygodium kaulfussii (Heer)

Genus Equisetaceae

Equisetum newberryi (Knowlton & Cockerell)

Genus Arecaceae

Sabal eocenica (Knowlton)

Genus Moraceae

Ficus tiliaefolia (Heer)

Ficus cr. goshenensis (Chaney & Sanborn)

Genus Magnoliaceae

Magnolia Leei (Knowlton)

Genus Anonaceae

Anona cf. coloradensis (Knowlton)

Genus LauraceaeNectandra cf. presanguinea (Chaney & Sanborn)Ocotea sp.Genus EuphorbiaceaeMallotus sp.Genus SapindaceaeCupania cf. oregona (Chaney & Sanborn)Genus DilleniaceaeTetracera sp.Genus CaprifoliaceaeViburnum simile (Knowlton)

In comparing the above forms with those identified from mid-continental and southwestern formations, LaMotte was strongly inclined to consider the Swauk flora as being Paleocene in age.

In comparing the above forms with those reported elsewhere in the State of Washington, LaMotte found that the flora of the Swauk formation is also present ". . . in the rocks exposed on the north fork of the Nooksack River in the Van Zandt quadrangle west of the Cascades near the international boundary." The flora common to the Swauk formation and the rocks of the Nooksack River area include the following forms:

Genus SchizaeaceaeAnemia occidentalis (Heer)Lygodium kaulfussii (Heer)

Genus EquisetaceaeEquisetum newberryi (Knowlton & Cockerell)Genus ArecaceaeSabal eocenica (Knowlton)Genus MoraceaeFicus titiaefolia (Heer)Ficus cr. goshenensis (Chaney & Sanborn)Genus MagnoliaceaeMagnolia leei (Knowlton)Genus DilleniaceaeTetracera Sp.Genus CaprifoliaceaeViburnum simile (Knowlton)

The rocks exposed along the north fork of the Nooksack River are part of the Chuckanut formation which may be equivalent, in part, to the rocks of the Nanaimo group of the San Juan Islands of northwestern Washington. Bradley (1950) states: "Conglomerates of the Chuckanut formation . . . are indistinguishable from the 'Cretaceous' conglomerates immediately above the Cretaceous faunal horizons. Thus the Nanaimo group may be in part post-Cretaceous."

The identification and correlations of the fossil leaves of the Swauk formation by Knowlton, Duror, Brown and LaMotte suggests that the Swauk formation is, for the most part, Paleocene in age. However, the limitations of paleobotanical

correlations and the preliminary status of the work must be recognized. Parts of the Swauk formation may be uppermost Cretaceous or early Eocene in age.

A lower Tertiary age is further suggested by other evidence. Weaver (1937) states: "The Teanaway basalt exposed in the eastern flanks of the Cascade Mountains in central Washington, may represent the time equivalent of the Metchosin volcanics. Stratigraphically, they occupy a position between the continental Swauk formation and the overlying sediments of the Roslyn formation. . . . The discovery of specimens of Turritella andersoni in stratified tuffs intercalated within the basaltic flows at Albert Head near Victoria indicates a middle Eocene age for the upper portion of the Metchosin volcanics."

A correlation between the Teanaway and Metchosin volcanics further suggests that the Swauk formation may be equivalent in age to the Solduc formation of the Olympic Mountains. "Both of these formations are folded and were eroded prior to the outpouring of the Teanaway volcanics in eastern Washington and the Metchosin volcanics in western Washington and Oregon." (Weaver, 1945).

Northeastern Chiwaukum Area

The northeastern quarter of Chiwaukum quadrangle includes the northwestern portion of the continuous belt of folded and faulted Swauk sediments that extends from Wenatchee quadrangle northwestward across Chiwaukum and southwestern

Chelan quadrangles. The region occupied by the Swauk formation is a wedge-shaped area of 125 square miles that is defined on the west and northeast by two faults that intersect a mile north of the summit of Basalt Peak.

The strata of the Swauk formation have been warped into open folds with northwest-southeast trending axes that are parallel to the trace of the fault that defines the Swauk formation on the northeast. The inclination of the strata in the limbs usually ranges between 25 and 65°, but nearly vertical to vertical beds may be observed in the southwestern part of the area.

The basal contact of the Swauk formation was not observed, but it presumably rests on the rocks of the Metamorphic Complex, with which it is in fault contact. At Natapoc Mountain, truncated strata of the Swauk formation are overlain by horizontal beds of conglomerate and intercalated sandstone of the Summit conglomerate (Fig. 38).

The Swauk formation is composed of a thick succession of intercalated coalescent sheets and lenses of arkose, shale, and conglomerate that have an inferred thickness that may exceed ten thousand feet. Arkose is the most common lithologic type and it is estimated from sparse outcrops to constitute over 75 per cent of the section exposed in this area. The beds range from less than one foot to over one hundred feet in thickness. They may be massive or cross-bedded. Shale is

PLATE NO. 32

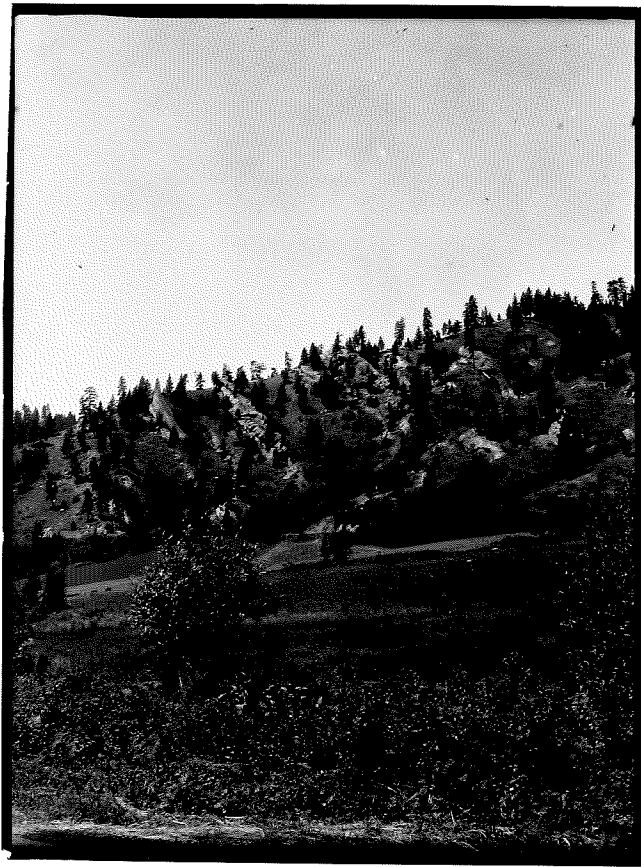


Fig. 32 - Photograph of Swauk strata on ridge southeast of Plain. The strata are inclined northeastward. The broad valley in the foreground is occupied by Little Chumstick Creek.

probably next in abundance, but this is only inferred from a few artificial and natural exposures. The beds are intercalated with arkose and rarely exceed a few feet in thickness. The contacts between the shale and arkose are sharp with rather even surfaces. No ripple marks or surface markings were observed on the bedding surfaces. Medium and coarse conglomerates constitute less than 5 per cent of the section, and they are not restricted to any part of the section or area. They are usually lenticular masses within the beds of arkose. Cut and fill structures with crescent-shaped lenses of conglomerate are not uncommon. The contacts between the lenses of conglomerate and arkose may be rather abrupt or grade gradually from one into the other.

The arenites are pale gray, massive or cross-bedded, fine to coarse-grained, usually well sorted, coherent or friable, biotite bearing arkoses with angular grains of nearly equal quantities of feldspar and quartz. They are usually medium to coarse-grained, but finer or coarser facies are not uncommon. The coarser facies are conglomeritic arkoses or actually fine conglomerates, and some of the rocks commonly classified as shale in the field are very fine-grained, laminated arenites. Size analyses were made of spot samples of arkose, the results of which are shown in Plate Nos. 33, 34 and 35. They have a sorting coefficient (S_o) of less than 2.5 which classifies them as well sorted. A sediment of normal

PLATE NO 33 — CUMULATIVE FREQUENCY CURVES FOR ARKOSE

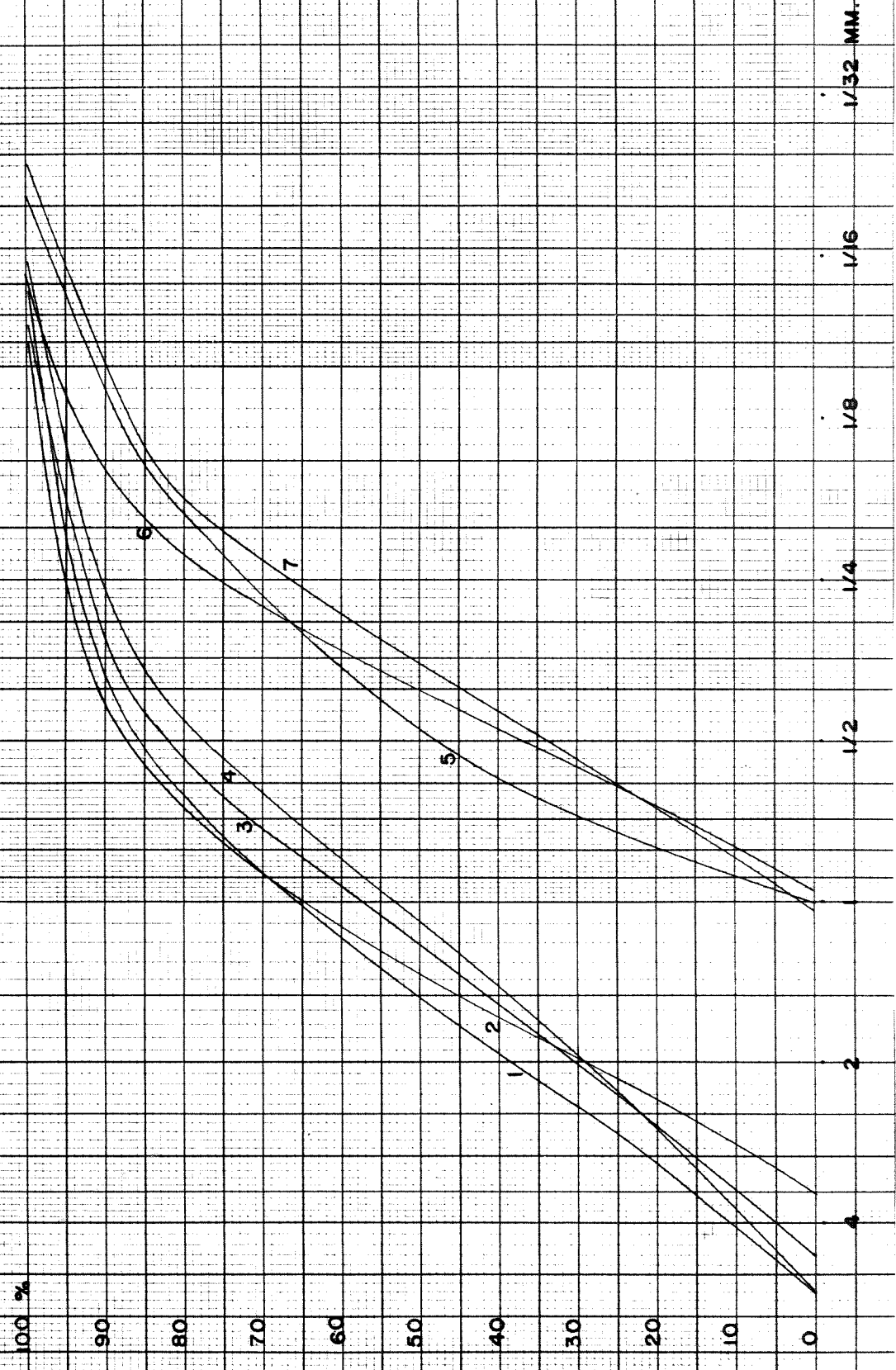


PLATE NO. 34

SIGNIFICANT VALUES FROM THE CUMULATIVE FREQUENCY CURVES

Sample Number	10 Percentile (P10)	25 Percentile (P25)	50 Percentile (P50)	75 Percentile (P75)	90 Percentile (P90)
1	4.00	2.75	1.47	0.762	0.412
2	2.56	2.14	1.36	0.762	0.360
3	3.50	2.33	1.20	0.63	0.30
4	3.71	2.25	1.04	0.54	0.231
5	0.88	0.75	0.475	0.222	0.108
6	0.790	0.600	0.400	0.250	0.157
7	0.820	0.592	0.350	0.200	0.095

PLATE NO. 35

STATISTICAL SUMMARY OF PERCENTILE MEASURES

Sample Number	(a) Median (Md)	(b) Skewness (Sk)	(c) Kurtosis (K)	(d) Coefficient of Sorting (So)
1	1.47	-0.736	0.28	1.90
2	1.36	-0.10	0.31	1.67
3	1.20	-0.70	0.27	1.92
4	1.04	-0.93	0.25	2.04
5	0.475	-0.019	0.34	1.84
6	0.400	-0.073	0.27	1.54
7	0.350	-0.107	0.27	1.72

(a) Md = 50 Percentile

(b) Sk = $P_{50} - 1/2(P_{10} + P_{90})$

(c) K = $(P_{25} - P_{75}) / 2(P_{10} - P_{90})$

(d) So = $\sqrt{P_{25} / P_{75}}$

sorting has a sorting coefficient between 2.5 and 3.0. The negative values of the skewness (Sk) show that their simple-frequency-curves are asymmetrical with maximum sorting of the sediments on the fine side of the median diameters (Md). A normal curve has a skewness of zero. The high values for the kurtosis (K) show that their frequency curves are steep with maximum sorting over a small-size range which further illustrates that the sediments are well sorted. A normal curve has a kurtosis of 0.263; a greater value signifies a steep curve (Tickell, 1938) as illustrated by the cumulative-frequency curves. Specimen No. 4 is the only exception which has a value of 0.25 for the kurtosis. Microscopic study of the arkoses (Fig. 33) shows that they consist of angular, detrital grains dominantly of quartz and plagioclase (An₂₂ to An₃₅) with subordinate quantities of brown biotite and minor quantities of micropegmatite, epidote, sphene, chlorite, microcline, microperthite, orthoclase, muscovite, apatite, garnet, magnetite, rutile, green hornblende and cryptocrystalline fragments of rocks. The grains are cemented, in part, with quartz. Interstitial argillaceous material is a very minor constituent.

The shales are brown to dark gray, moderately laminated, arenaceous siltstones which are usually coherent but may be very friable. Moderately to well preserved fossil leaves are sometimes present. The shales have a mineral assemblage that is related to the arkoses. They consist mostly of

PLATE NO. 36

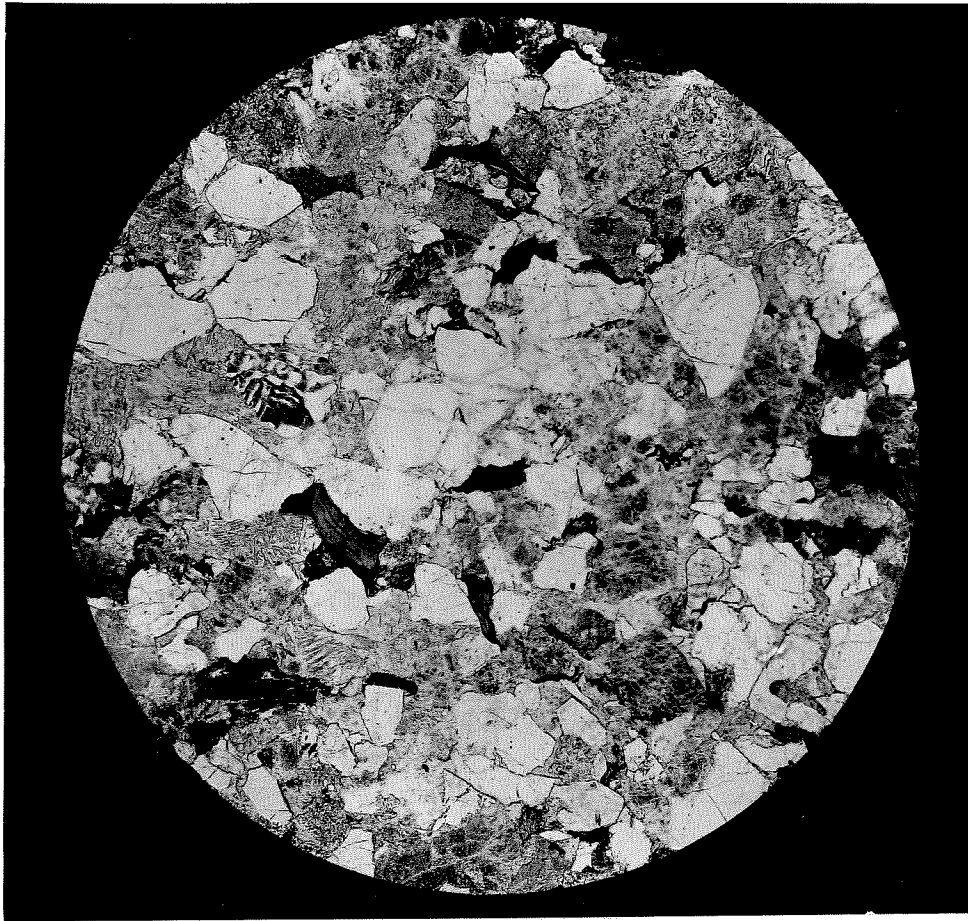
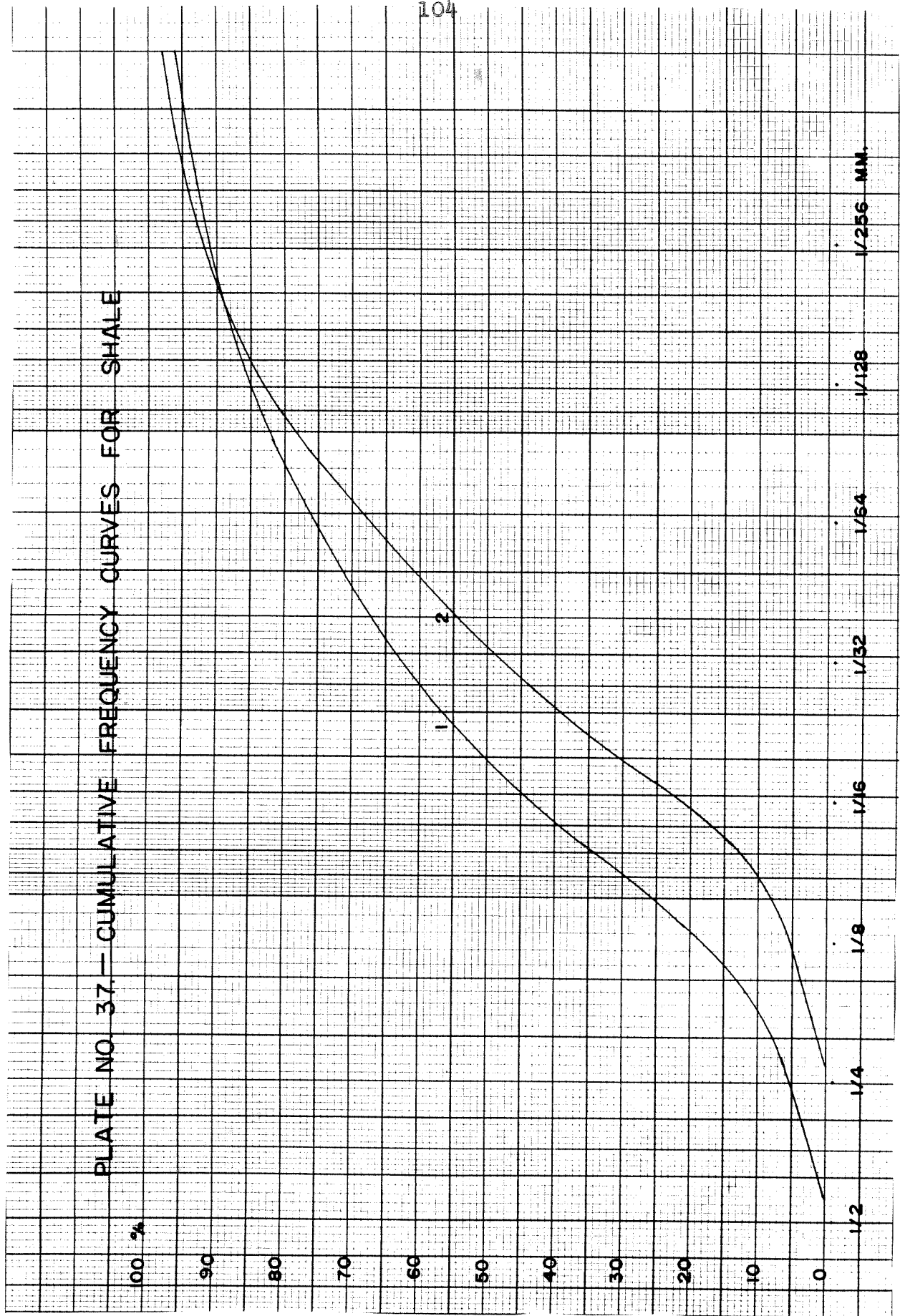


Fig. 33 - Photomicrograph of arkose from the Swauk formation. It consists dominantly of angular grains of quartz and feldspar. Other minerals are biotite, epidote, sphene, apatite, garnet, muscovite and magnetite. A few rock fragments are also present. (Plain light; X20)

quartz, feldspar and biotite with minor quantities of chlorite, muscovite, magnetite, hornblende, rutile, zircon and epidote. Size analyses of two specimens of shale are shown in Plate Nos. 37, 38 and 39. They consist of variable quantities of silt and fine sand with only small quantities - less than 10 per cent - of clay size particles. They are rather well sorted with sorting coefficients (S_o) of 2.48 and 2.20. However, they are not as well sorted as the arenites, but this is a normal relationship. Maximum sorting of the sediments is on the fine side of the median diameters (M_d) as shown by the negative values of the skewness (S_k). The values of kurtosis (K) are lower than those for the arenites which is readily illustrated by the more gently sloping cumulative-frequency curves of the shales.

A medium to coarse conglomerate that consists of sub-angular to rounded phenoclasts of rock types that are related to the adjacent rocks of the Metamorphic Complex is present along the north shore of Wenatchee Lake at the foot of Dirty Face Peak. It may be a basal conglomerate of the Swauk formation, but its relationship with the underlying and overlying rocks was not observed due to overburden and brush. Elsewhere the conglomerates are polymitic with rounded to subangular phenoclasts of rhyolite, milky quartz, granophyre, granophyric granodiorite-porphyre, aplite, quartz diorite, granodiorite, etc. in an arenaceous matrix with a composition of arkose. Phenoclasts from shale of the Swauk formation are sometimes

PLATE NO. 37.— CUMULATIVE FREQUENCY CURVES FOR SHALE



SIGNIFICANT VALUES FROM THE CUMULATIVE FREQUENCY CURVES

Sample Number	10 Percentile (P10)	25 Percentile (P25)	50 Percentile (P50)	75 Percentile (P75)	90 Percentile (P90)
1	0.175	0.102	0.050	0.0165	0.0046
2	0.090	0.056	0.029	0.0115	0.005

PLATE NO. 39

STATISTICAL SUMMARY OF PERCENTILE MEASURES

Sample Number	(a) Median (Md)	(b) Skewness (Sk)	(c) Kurtosis (K)	(d) Coefficient of Sorting (So)
1	0.050	-0.0398	0.249	2.48
2	0.029	-0.018	0.262	2.20

(a) Md = 50 Percentile

(b) Sk = $P_{50} - 1/2(P_{10} + P_{90})$

(c) K = $(P_{25} - P_{75}) / 2(P_{10} - P_{90})$

(d) So = $\sqrt{P_{25} / P_{75}}$

present. The phenoclasts range in size from a fraction of an inch to three inches in diameter with the coarse sizes being less common. Individual deposits have phenoclasts of rather uniform size which suggests moderate sorting. No size analyses were made of these deposits.

Origin

The Swauk formation is interpreted as being deposited, for the most part, by large streams which built coalescent sheets and lenses of alluvial detritus by lateral shifting of their courses. This is illustrated in the field by coalescent sheets and lenses of arkose and subordinate quantities of shale and conglomerate, cross bedding, and cut and fill structures with the occasional presence of phenoclasts of shale from the Swauk formation. Further evidence lies in the petrographic character of the arkose. It is usually well sorted and clean without appreciable quantities of clay or silt. This suggests an oxidizing terrestrial environment not capable of flocculation of the fine clastic particles which would permit concurrent deposition with the sand.

The great thickness and areal distribution of the Swauk formation along with its high content of feldspar, the index mineral of relief, bears witness that the sediments were, for the most part, derived from granitic massifs of strong relief. The position of this area is not definitely known, but its relative position with respect to the present distribution

of the Swauk formation may be inferred from the character of the deposits and composition of the sediments.

The sediments of the Swauk formation are not fan-glomerate or delta deposits, but they are floodplain and channel deposits which were laid down somewhere between the other two environments of deposition. Therefore, it may be suggested that the strongly uplifted granitic massifs, from which the sediments were being derived, were not immediately adjacent to the present outcrops of the Swauk formation. This is further supported by the composition of the sediments which, except in basal beds, do not reflect the diverse character of the adjacent rocks of the basement complex. If the Mt. Stuart massif furnished large quantities of sediments, then it is reasonable to assume that sediments were derived from the staurolite and kyanite bearing Chiwaukum schist (Page, 1939) as well as from the quartz diorite and granodiorite. Staurolite and kyanite were not observed or have they been reported from sediments of the Swauk formation. Hornblende schists are common both east and west of the belt of Swauk sediments, but hornblende is a very minor constituent of the sediments. The biotite gneiss, the staple rock of the Swakane gneiss (Waters, 1930), is usually too fine-grained to furnish the coarse grains of feldspar found in the arkose. The great thickness of Swauk sediments that are in fault contact with the older rocks also suggests that the sediments may have extended well beyond their

present boundaries.

The mineral assemblages of the arkose series suggest that the granitic massifs were composed of quartz diorite and granodiorite with a mineral composition similar to those rocks of the Chelan batholith. Such rocks are extensively exposed in the areas to the northeast. The Okanogan Highlands may have been the source area for part of the Swauk sediments.

The evidence presented in the foregoing sections supports the hypothesis that central Washington was part of a widespread, subsiding coastal plain during the time of Swauk sedimentation. This hypothesis was first inferred by Knowlton (1889) who states: "A number of species of plants have been found to be common on the east and west sides of the Cascades. This number is not large, but they are important and easily recognized forms, and there is indication that the number will be increased when the material in hand has been more thoroughly studied. This would indicate that approximately similar conditions of climate and topography prevailed throughout this general area during the Puget epoch." This old coastal lowland was first defined by Weaver (1937, 1945) as possibly extending westward from Idaho to and beyond the present position of the coast and southward from British Columbia into Oregon. The total sinking or downwarping of this plain was sufficient in places to permit the accumulation of over 12,000 feet of continental sediments during the time of Swauk sedimentation.

The Swauk formation is interpreted as being part of a widespread lithologic unit of continental sediments that may have covered most of the old coastal lowland of central and western Washington. It is possible and probable that this unit is represented in western Washington, at least in part, by sediments of the lower Puget group (Weaver, 1937), Solduc formation (Weaver, 1945), Chuckanut formation (Weaver, 1937) and upper Nanaimo group (Bradley, 1950).

Post-Swauk Intrusives

The post-Swauk intrusives consist of diabase and hornblende-dacite-porphry. They may be more common in the area than indicated below. It is most probable that some are concealed from observation by the extensive overburden.

Diabase

Diabase is present as two dikes and a sill. A dike was observed south of the headwaters of Thomson Creek, and another on the south fork of Beaver Creek. They appear to occur along the fault contacts between the Swauk formation and the older rocks of the Metamorphic Complex, but the exposures are poor, and their contacts with the country rock are not observed. The sill extends from Natapoc Mountain southward for a distance of three miles (Page, 1939) and has an average thickness of approximately twenty feet. The overlying and underlying sediments

show negligible effects of baking.

The diabase is a grayish-black, aphanitic rock that sometimes shows vesicular and amygdaloidal structures. In thin sections (Figs. 34 and 35), when examined under the microscope, a diabasic texture is revealed with subhedral to anhedral crystals of augite between the laths of labradorite which have a maximum length of five-tenths of a millimeter. Variable quantities of brown, residual glass is also present between the crystals of feldspar. Small grains of magnetite are common and always present. The amygdales are composed of analcime and have an average diameter of five millimeters. They may or may not be present. Olivine is a minor constituent of the rock, and was only observed in the specimens of diabase from the dike south of the headwaters of Thomson Creek. It is sometimes altered, in part, to iddingsite (Fig. 35).

The diabase dikes are post-Swauk in age, and their presence along the faults suggests that they were emplaced during or sometime after faulting. Their occurrence and petrographic character suggests that they may be related to the Teanaway basalt which has been designated by Weaver (1937) as Lower to Middle Eocene in age, evidence for which has been given in a previous section. In the Mt. Stuart quadrangle, the Swauk formation is cut by numerous diabase dikes which widen out in their upper portions and pass into the basal flows of the overlying Teanaway basalt (Weaver, 1937). It is possible

PLATE NO. 40



Fig. 34 - Photomicrograph of diabase sill south of Natapoc Mountain showing grains of augite among microlites of labradorite. Some basaltic glass is also present. (Plain light; X54)

PLATE NO. 41



Fig. 35 - Photomicrograph of diabase dike near headwaters of Thomson Creek showing a phenocryst of olivine in a trachitic matrix of augite and labradorite. The olivine is altered, in part, to iddingsite. (Plain light; X54)

that the emplacement of these dikes was controlled by the formation of fissures in the Swauk formation by a deep-seated fault or faults which may be a continuation of the north-south trending fault that defines the Swauk formation on the west in northeastern Chiwaukum quadrangle. However, this evidence is not conclusive, and the diabase in the area under consideration may be related to the Yakima basalt of Miocene age.

Hornblende-Dacite-Porphry

Hornblende-dacite-porphry occurs at Basalt Peak as an asymmetrical laccolith which has a maximum thickness of nearly 2000 feet. It is poorly exposed except on its western margin where one may observe the dacite in contact (concordant) with a shale member of the Swauk formation. The contact is sharp, and optalic metamorphism of the shale is negligible. The laccolith is defined on the northeast and northwest by two intersecting faults, along which the feeders for the laccolith appear to occur. Small areas of fault breccia composed of biotite-gneiss and arkose may be observed at several places along the crest of the laccolith. Exposures are not present on the south slope of Basalt Peak, therefore, the contact between the dacite and Swauk formation is only inferred from the topography.

The hornblende-dacite-porphry has a gray, aphanitic matrix with euhedral to anhedral phenocrysts of feldspar, hornblende and quartz, named in the order of their decreasing

abundance. The phenocrysts constitute about 40 per cent of the rock by volume. The phenocrysts of feldspar, hornblende and quartz have maximum diameters or lengths of four, seven, and four millimeters respectively.

In thin section (Fig. 36), when examined under the microscope, the rock is seen to consist of a cryptocrystalline matrix with phenocrysts of plagioclase, hornblende and quartz. The plagioclase frequently shows zoning and ranges in composition from andesine (An_{37}) to labradorite (An_{60}) with the cores being more calcic than the outer rims. The plagioclase may be present as single, euhedral to subhedral crystals or as clusters of crystals (glomerophytic). It is commonly altered, in part, to sericite and carbonate, and reaction rims are sometimes observed. The hornblende is usually altered to an aggregate of chlorite and carbonate which is pseudomorphous after it, but unaltered hornblende with X yellowish-green, Y olive green and Z dark green is common in some sections. It is euhedral to subhedral in form and is seriate with lengths or diameters ranging from seven millimeters to minute sizes. Quartz is common but subordinate to plagioclase and hornblende. It is present as anhedral to subhedral crystals with a maximum diameter of four millimeters. It is commonly corroded with the formation of embayments. Magnetite is present throughout the rock as euhedral to anhedral grains with a maximum diameter of one-tenth millimeter. Minute, prismatic crystals of apatite

PLATE NO. 42

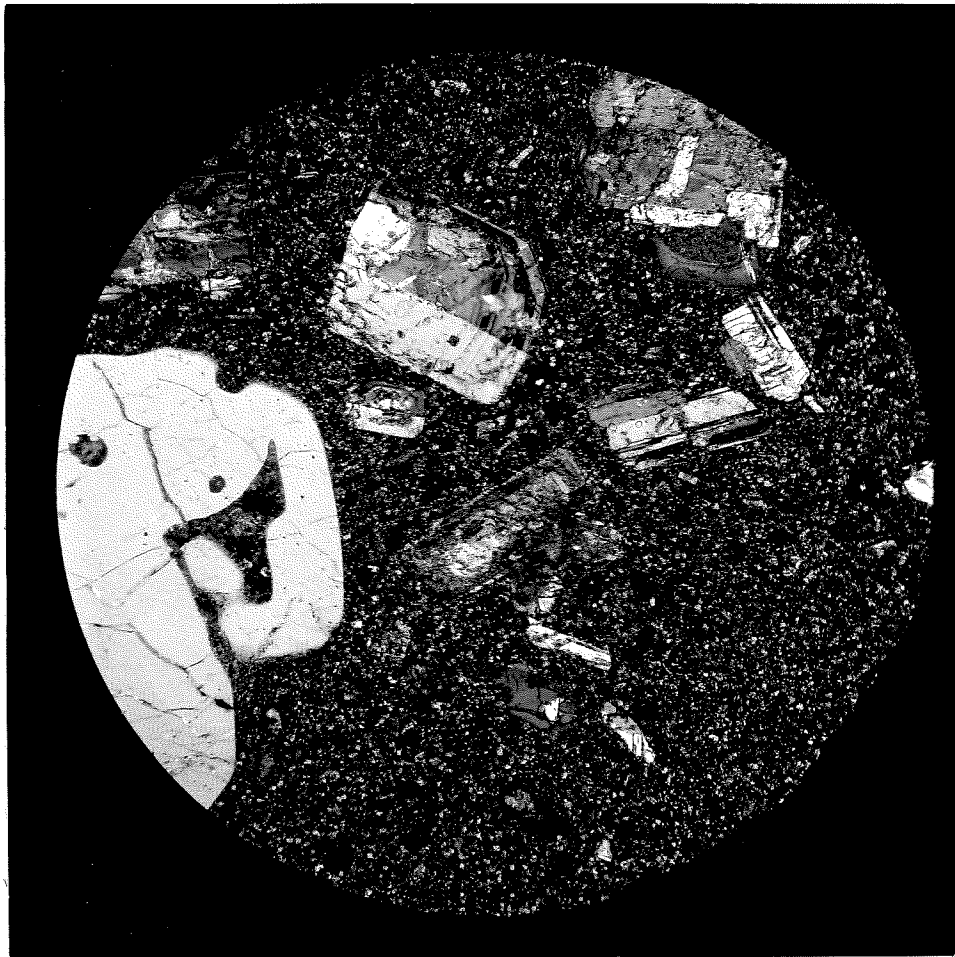


Fig. 36 - Photomicrograph of hornblende dacite porphyry from Basalt Peak showing phenocrysts of plagioclase and quartz. (Plain light; X20)

are frequently observed but only in small quantities.

The age of the hornblende-dacite-porphyry is not definitely known. It was emplaced during or after faulting and before the Swauk sediments were flushed out of the graben during the Twisp stage of erosion.

Hypersthene-Andesite-Porphyry

Hypersthene-andesite-porphyry occurs at Sugarloaf Peak as a relic lava cap (Page, 1939). It occupies an area of six-tenths of a square mile and has a maximum thickness of approximately 200 feet. Its contact with the underlying metamorphic rocks is not exposed, but it appears to rest on a surface of very moderate relief that is closely related to the present surfaces directly northwest and southeast of Sugarloaf Peak. Columnar jointing may be observed west of the summit of Sugarloaf Peak where the andesite is best exposed. A platy parting, which has a southwestward dip of 4° , is well developed and may be due to flow structure.

The andesite has a medium-gray, aphanitic groundmass with abundant small phenocrysts of euhedral to subhedral feldspar and pyroxene, the latter being subordinate. It has a platy structure that is usually conspicuous in the field and in hand specimen.

In thin section (Fig. 37), when examined under the microscope, the rock is seen to consist of approximately 40 per

PLATE NO. 43

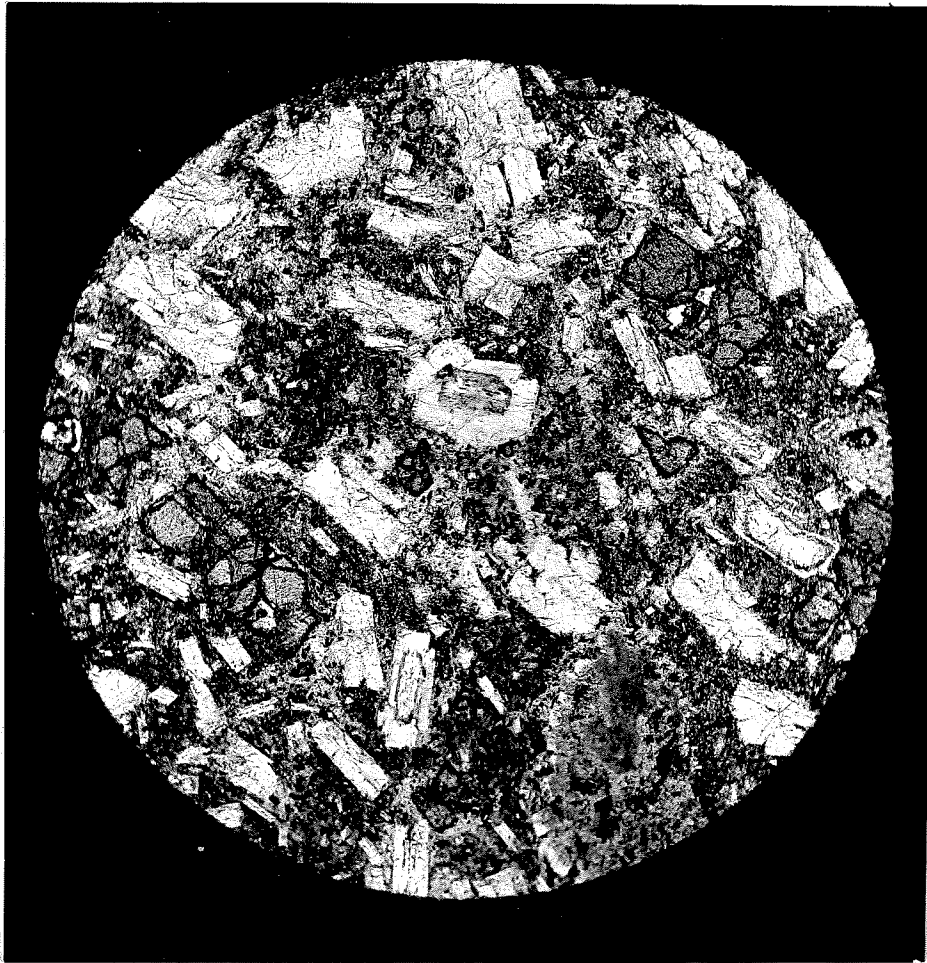


Fig. 37 - Photomicrograph of hypersthene andesite porphyry from Sugarloaf Peak showing phenocrysts of hypersthene and plagioclase. (Plain light; X20)

cent of phenocrysts of plagioclase (An_{39} to An_{62}) and hypersthene, the latter being subordinate, in a microcrystalline matrix of andesine with numerous minute crystals of magnetite. The phenocrysts of plagioclase are euhedral to subhedral in form with a maximum length of 1.5 millimeters. Inclusions of glass are common. Hypersthene is present as seriate, euhedral to subhedral phenocrysts with a maximum diameter of 1.5 millimeters. It is distinctly pleochroic with X brown, Y yellowish-brown, and Z pale green.

The age of the hypersthene-andesite-porphry is not definitely known, but its age may be inferred from the age of the relic late-mature topography upon which it appears to rest. The author considers the relic topography of the Entiat Mountains to be post-Miocene in age, evidence for which will be given in a following section. The petrographic character of the andesite further suggests that it may be related in time to the hypersthene-andesites of Pliocene or early Pleistocene age.

Summit Conglomerate

The Summit conglomerate was named, mapped and described by Page (1939) in conjunction with his work in southeastern Chiwaukum quadrangle. The conglomerate had been previously mentioned by Hougland (1932).

The Summit conglomerate is restricted in its known distribution to Natapoc Mountain where horizontal beds of the

Summit conglomerate rest upon truncated strata of the Swauk formation which have a westward inclination of 35° . It occupies an area of one-eighth of a square mile and may exceed 200 feet in thickness. For the most part, it is poorly exposed, but its contact with the underlying Swauk formation is well exposed along its southern border (Fig. 38).

In describing the appearance and character of the Summit conglomerate, Page (1939) states: "The Summit formation is chiefly conglomerate, light gray to cream in color. Stratification is very distinct but rude, the beds varying in thickness along the strike. Consolidation is poor to fair; probably there is no cement.

"The pebbles, cobbles, and boulders are sub-angular to well rounded, most of them showing some rounding and some showing a great deal. The materials are only moderately sorted. Some strata 1 to 2 feet thick are almost pure sand with occasional boulders; others are gravel with only about 20% sand; and some layers (perhaps 6 feet thick) are made up mainly of boulders and pebbles 6 inches to 5 feet in diameter.

"The coarse detritus includes some serpentine, granodiorite, biotite gneiss, aplite and pegmatite, but probably more than 90% is basalt or dark andesite. It is dark purplish-gray with opaque white phenocrysts or in some cases vesicules. There are a few breccia beds of well-cemented very angular basalt fragments; one of these is near the highest point of the

PLATE NO. 44

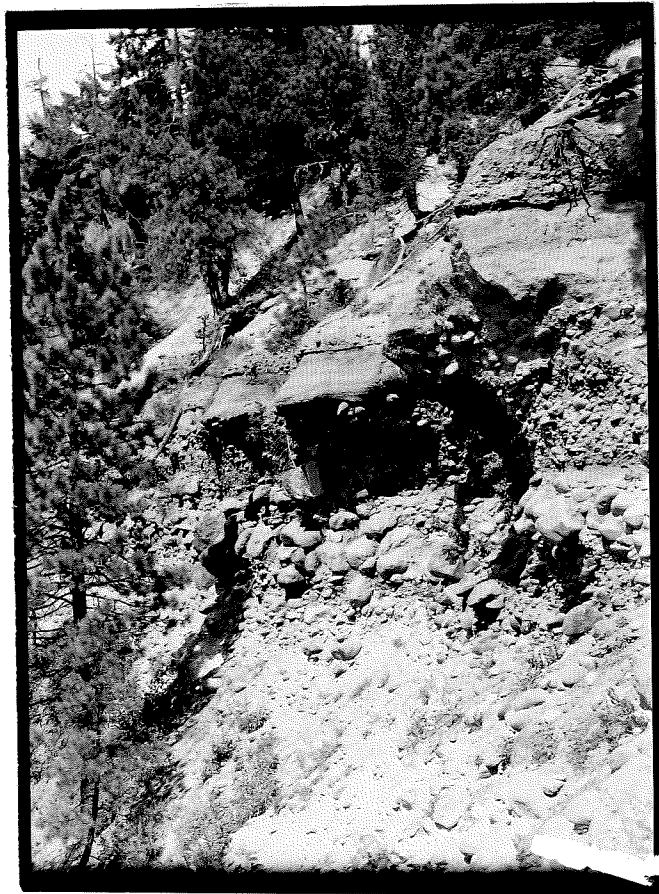


Fig. 38 - Photograph of basal portion of the Summit conglomerate on the south slope of Natapoc Mountain.

summit. Pebbles of the Swauk sandstone were not observed, but possibly some of the cobbles and pebbles came from Swauk conglomerate."

The author found andesite to be the common rock type in his collection of phenocrasts from the Summit conglomerate. Megascopically, the andesite has numerous, small phenocrysts of grayish-white feldspar and subordinate quantities of black pyroxene in a gray to bluish-black, aphanitic matrix. In thin section (Fig. 39), when examined under the microscope, the rock consists of phenocrysts, 30 per cent by volume, of plagioclase, hypersthene, augite, and pigeonite in a cryptocrystalline or hyaline matrix, the character of which controls the color of the rock. Those rocks with a cryptocrystalline matrix are gray, and those with a glassy matrix are bluish-black in color. The plagioclase phenocrysts are euhedral to subhedral in form, and have a maximum length of two millimeters. They range in composition from sodic-labradorite to calci-andesine and frequently show zoning with the cores more calci than the outer rims, but oscillations may be observed. Inclusions of glass are common. Hypersthene, with X light brown, Y pale brown, and Z light green, is the most common pyroxene. It is present as euhedral to subhedral, prismatic crystals with a maximum length of 1.5 millimeters. Augite and pigeonite, with a 2V of 60 to 15° respectively, are minor but conspicuous constituents. They vary in form from euhedral to anhedral crystals with a maximum

PLATE NO. 45

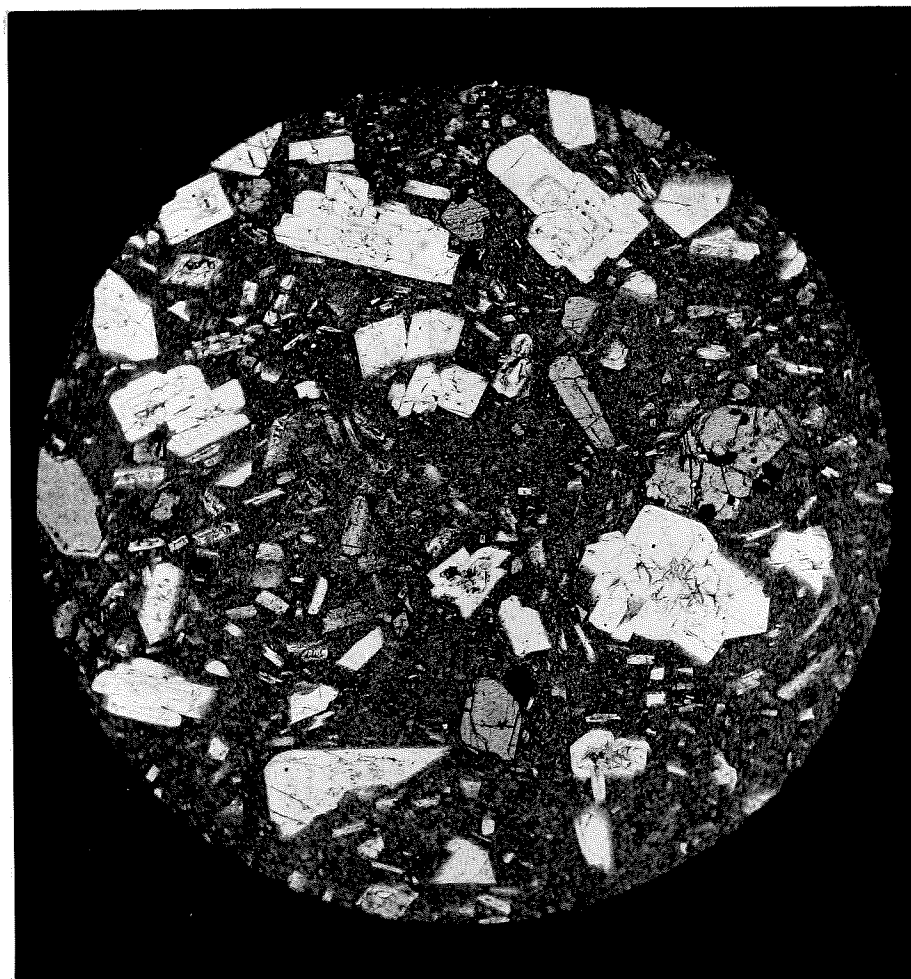


Fig. 39 - Photomicrograph of pyroxene andesite porphyry from Summit conglomerate showing phenocrysts of pyroxene and plagioclase. The pyroxene is hypersthene and subordinate quantities of pigeonite and augite. (Plain light; X20)

diameter of one millimeter. Euhedral to subhedral crystals of magnetite with a maximum diameter of one-tenth millimeter are common.

The Summit conglomerate is interpreted to be of fluvial origin, an interpretation that was also held by Page (1939). Such an origin is suggested by the presence of moderately sorted conglomerates with intercalated lenses of sand and by the degree of rounding of the phenoclasts (Fig. 39).

The topographic position of the surface upon which the Summit conglomerate rests suggests that the time of deposition was before the late Tertiary uplift that give rise to the Twisp stage of erosion and the Cascade Mountains. It is possible that the Summit conglomerate was deposited in a valley of the Entiat surface.

Superficial Deposits

The superficial deposits consist of glacial deposits, alluvial deposits and slope wash. These deposits were not studied in any detail and are not within the scope of this report. The heavy overburden of soil, brush and timber would make a detailed study very difficult if not impossible without resorting to trenching.

Glacial deposits are abundant in the Wenatchee Valley. A moraine is present around the east end of Wenatchee Lake which extends northwestward along the edge of the lake and northward

across the valley. A lateral moraine is present along the south slope of Pole Ridge north of Fish Lake. Erratics are scattered over the hills east and southeast of Fish Lake at elevations that exceed 800 feet above the valley floor. Till is present in the Wenatchee Valley east of Wenatchee Lake nearly to the town of Plain where it appears to pass into glaciofluvial deposits which extend southward in the valley for a distance of approximately four miles.

The deposits described above were largely deposited by the Wenatchee Glacier (Russell, 1898-1899) which was formed by the convergence of glaciers occupying the Little Wenatchee and White River valleys west of the area under consideration. East of Fish Lake the Wenatchee Glacier converged with a glacier occupying the valley of Chiwawa River, but the extent or influence of this glacier is not known.

According to Russell (1898-1899), a glacier also occupied the valley of Nason Creek. The deposits in this valley were not studied.

It is very probable that there was more than one stage of glaciation. According to Page (1939), there were three stages of glaciation in the vicinity of Leavenworth south of the mapped area. The moraine around the east end of Wenatchee Lake may be a terminal moraine deposited by the last advance of the glacier. Such an interpretation would be in harmony with the work of Page (1939) who found the last glacial advance to be the

least extensive.

The alluvial deposits are largely restricted to the larger valleys. They consist of coarse clastic material which is, in part, derived from the glacial deposits of the valley.

Small alluvial fans are sometimes present on the edge of the valleys. They are formed by small intermittent streams on the valley walls.

Slope wash is the most widespread superficial deposit. Most of the slopes are partially or completely covered with this deposit.

Inclusions of amphibolite occur in the granitic rocks of the Chelan facies. The foliation of the inclusions and enclosing granitic rocks have a common attitude which conforms with the regional structure of the rocks of the Metamorphic Complex (Plate No. 47).

The foliation of the crystalline schists of the Metamorphic Complex at Dirty Face Peak on the western side of the Swauk filled graben closely conforms to the attitude of the foliation of the crystalline schists of the Entiat Mountains suggesting a continuity in structure over a large area (Plate No. 46).

The contact between the non-granitized schists and granitic rocks at Dirty Face Peak is transitional and discordant. The attitude of the foliation does not change as it passes from the schists into the granitic rocks (Plate No. 46).

Inclusions of amphibolite are also present in the granitic rocks at Dirty Face Peak. The foliation of the inclusions is parallel to the foliation of the enclosing granitic rocks, and it conforms to the regional structure of the rocks of the Metamorphic Complex.

On Nason Ridge, the attitude of the foliation changes to a southeastward dip which ranges between 15 and 30°. This change in attitude may be local. Its areal distribution must await further study west of the area under consideration in this paper. It is possible that the reversal in attitude of

the foliation is a continuation of the anticlinal structure of the foliation of the Swakane gneiss of the Entiat Mountains of southwestern Chelan quadrangle which has been reported and described by Waters (1930).

Lit-par-lit structures are prominent on Nason Ridge. The foliation of the alternating layers of schist and permeation gneisses have a common attitude.

The foliation of the crystalline schists of the Metamorphic Complex was probably produced by intense deformation which gave rise to inclined and recumbent isoclinal folds. Due to sparse outcrops, this cannot be conclusively demonstrated in northeastern Chiwaukum quadrangle. However, the presence of isolated pods of marble supports such an hypothesis.

The anticlinal structure of the foliation of the crystalline schists of the Metamorphic Complex may be due to later warping along northwest-southeast trends. The axial trace of the anticlinal structure of the foliation bears north 65° (approximate value) west. The structure is truncated by two major faults of early Eocene age which are undoubtedly younger. The major fault that defines the Entiat Mountains on the west and the Swauk filled graben on the east bears north 30° west, and the major fault that defines the Swauk filled graben on the west bears nearly north-south.

Tertiary Structures

Early Tertiary Structures

During Paleocene and possibly beginning in late Cretaceous, a widespread coastal lowland which may have extended southward from British Columbia into Oregon and westward from Idaho to and beyond the present position of the coast was differentially downwarped. In the area of Chiwaukum quadrangle, downwarping was sufficient to permit the accumulation of over 12,000 feet of continental sediments, the Swauk formation.

Anticlinal Structures. According to Chappell (1936), minor folding of the Swauk strata took place in the area of Wenatchee quadrangle during the time of deposition. The results of contemporaneous folding were observed by Chappell at one locality and have not been reported elsewhere.

After deposition of the Swauk formation and before the outpouring of the basaltic lavas of the Teanaway basalt of early Eocene age, the Swauk strata were warped into folds with northwest-southeast trending axes and eroded to an uneven surface (G. O. Smith, 1904).

In Chiwaukum quadrangle, the strata of the Swauk formation were warped into open folds with axial traces bearing north 30° west. The inclination of the strata in the limbs of

the folds usually ranges between 25 and 65°, but nearly vertical to vertical beds may be observed in the southwestern part of the area under consideration. These structures are illustrated on the geologic map (Plate No. 46) and cross-section (Plate No. 47).

A major anticline in the Swauk formation extends south-southeastward from Fish Lake (Plate No. 46) into Wenatchee quadrangle,¹ a distance of thirty-four miles. The axial trace of the anticline bears north 30° west, and it is parallel to the trace of the fault that defines the Swauk filled graben on the east and the Entiat Mountains on the west. It is transverse to the structures in the rocks of the Metamorphic Complex which bear north 65° west.

Three inliers of rocks of the basement complex are present along the crest of the anticline in southeastern Chiwaukum (Page, 1939) and southwestern Chelan (Waters, 1930) quadrangles. The southernmost inlier is the largest, and it occupies an elongate area that extends across southwestern Chelan quadrangle into southeastern Chiwaukum quadrangle.

Faults. In northeastern Chiwaukum quadrangle, over twelve thousand feet of Swauk strata were placed in fault contact with the rocks of the Metamorphic Complex along two

¹ The anticline was mapped by Page (1939) in southeastern Chiwaukum quadrangle and by Chappell (1936) in Wenatchee quadrangle.

major faults (Plate No. 47) that intersect a mile north of the summit of Basalt Peak. The Swauk filled graben thus produced is one of the major structural features of Chiwaukum quadrangle.

The trace of the fault that defines the graben on the northeast has been mapped¹ northwestward from the northern boundary of Wenatchee quadrangle to the northern boundary of Chiwaukum quadrangle, a distance of forty miles. It extends northwestward of Chiwaukum quadrangle an unknown distance. It probably extends southeastward into Wenatchee quadrangle where 6,000 to 10,000 feet of Swauk strata are inclined eastward toward the Columbia River; only the lower portions of the Swauk formation are present east of the Columbia River.²

The trace of the fault that defines the graben on the west has been mapped intermittently from Basalt Peak to the southern boundary of the area under consideration. It may continue southeastward into southeastern Chiwaukum quadrangle, but, according to Page (1939), its presence is uncertain. Are the hundreds of fissures that are occupied by the feeders of the flows of the Teanaway basalt related to deep-seated faults?

1 The trace of the fault was mapped by Waters (1930) in southwestern Chelan quadrangle and by Page (1939) in southeastern Chiwaukum quadrangle.

2 H. A. Coombs, personal communication.

The answer to this question must await future work.

Although an actual contact between the strata of the Swauk formation and the older rocks of the Metamorphic Complex was not observed, the presence of a fault contact is strongly suggested by many features characteristic of faults. These features are discussed in the following paragraphs.

Several features characteristic of fault planes may be observed along the contact between the strata of the Swauk formation and the rocks of the Metamorphic Complex. They are fault breccia, gouge, micro-breccia, mylonite, and slickensides. For the most part, these features are concealed beneath a thick mantle, but their presence can be established from scattered outcrops along the contact.

Truncated strata of the Swauk formation are illustrated in the geologic cross-section (Plate No. 47). Approximately 12,000 feet of exposed strata on each limb of the anticline are inclined toward the contacts while only a few thousand feet of strata are inclined away from the contacts.

Truncated strata are further illustrated on Pole and Nason Ridges where moderately inclined¹ strata suddenly end and abut against a nearly vertical surface of the rocks of the Metamorphic Complex. The nearly vertical attitude of the con-

1 Eastward inclination between 15 and 40°.

tact is shown on the geologic map (Plate No. 46) by the straightline character of the trace of the contact as it crosses the two mountain ridges.

The lithologic character of the Swauk strata at the contacts does not suggest a depositional contact but rather a fault contact. The composition of the strata, mostly arkose and shale, is uniform along the strike of the contact and does not reflect the composition of the adjacent rocks of the Metamorphic Complex. In previously described areas to the south, the composition of the basal beds of the Swauk formation is related to the composition of the underlying rocks of the basement complex.

The foliated structure displayed by the crystalline schists of the Metamorphic Complex is truncated by the nearly vertical contacts between the strata of the Swauk formation and the rocks of the Metamorphic Complex. The attitude of the foliation of the crystalline schists conforms to a regional structure that has been previously described. There is no evidence to suggest intense folding of the rocks of the Metamorphic Complex. On the other hand, the structures suggest that deformation was accomplished by faulting.

As previously inferred, the straight-line character of the traces of the contacts suggests faulting. If the contact was depositional, small ridges of the older rocks would project into the strata of the Swauk formation unless the surface on

the older rocks was very flat.

A fault is present on the east side of the largest inlier of rocks of the Metamorphic Complex (Waters, 1930; Page, 1939). In southwestern Chelan quadrangle, the strata of the Swauk formation are in fault contact with the metamorphic rocks of the inlier, but, according to Page (1939), the fault diverges somewhat from the inlier as the fault is traced north-northwestward into Chiwaukum quadrangle. The fault has not been observed north of the junction of Eagle and Van Creeks where it is expressed by a number of subsidiary normal faults in the Swauk strata (Page, 1939).

The trace of the fault along the inliers is parallel to the axial trace of the anticline and is also parallel to the trace of the fault that defines the graben on the east and the Entiat Mountains on the west. The close association and relationship between the folds in the Swauk formation, the inliers, and the faults strongly suggest that folding of the Swauk strata was associated with faulting of the rocks of the basement complex. This interpretation is further suggested by the relationship between the structures of the Swauk formation and the attitude of the foliation of the rocks of the Metamorphic Complex which has been previously described in this section. The attitude of the foliation conforms to a broad regional structure which is transverse to the axial traces of the folds in Swauk formation. There is no evidence to suggest that the

rocks of the Metamorphic Complex were warped into folds conforming with the folds in the overlying strata of the Swauk formation.

Late Tertiary Structures

In the late Tertiary time, further deformation took place along the northwest-southeast structural trends. It is illustrated by several folds in the flows of the Yakima basalt southeast and south of the area under consideration. An anticline, the Badger Mountain uplift, was formed southeast of the Entiat Mountains, and another, the Wenatchee Mountain uplift, was produced southeast of Mt. Stuart, the highest erosional remnant in the Cascade Mountains. These two anticlines are separated by a broad downwarp which is southeast of the Swauk filled graben in Chiwaukum quadrangle.

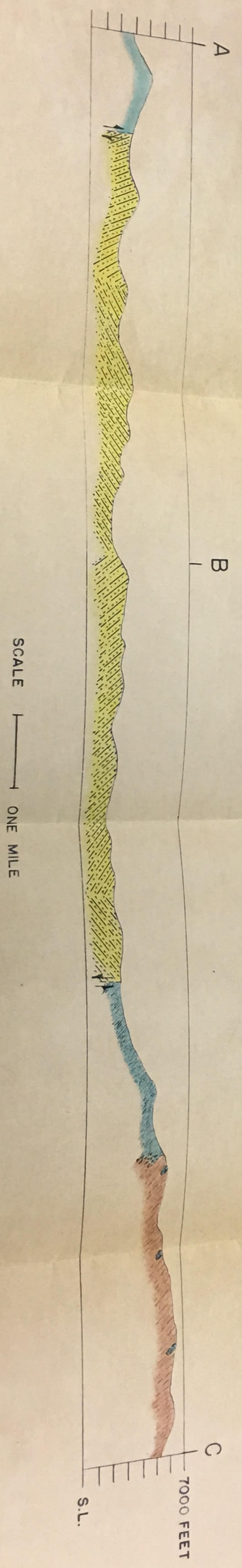
The folding of the flows of the Yakima basalt may be due to differential movement along faults in the underlying rocks of the basement complex. It is important to note that the Entiat Mountains, which are a continuation of Badger Mountain, are parallel to and defined on the west by a major fault with a possible throw of approximately 10,000 feet. In other words, the trend of the Entiat Mountains is controlled by faulting. Furthermore, as previously described in this section, the attitude of the foliation of the crystalline schists (internal structure) of the Entiat Mountains is transverse to the trend of the range. In Chiwaukum quadrangle, the foliation

of the crystalline schists has a strike of approximately 65° west of north and a northeastward dip that ranges between 25° and 70° . The trend of the Entiat Mountains bears north 30° west. The southeastward flowing drainage of the Entiat Mountains gives further support to this hypothesis.

In late Pliocene or early Pleistocene time, the area now occupied by the Cascade Mountains was warped into a major, broad upwarp with a north-south trending axis. This structure was superposed on the earlier northwest-southeast structural trends.

The relative age of the folds in the flows of the Yakima basalt with respect to the main structural trend of the Cascade Mountains is not certain. They may have been earlier, but there is no evidence to confirm two stages of uplift. It is possible that they were formed contemporaneously with the production of the main trend of the Cascade Mountains.

PLATE NO. 47. — GEOLOGIC SECTION ALONG LINE A-B-C ON MAP, PLATE NO. 46.



PHYSIOGRAPHY

Entiat Mountains

The Entiat Mountains occupy the northeastern portion of Chiwaukum quadrangle. They extend northwestward to the crest of the Cascade Mountains and southeastward to Badger Mountain east of the Columbia River where the trend swings eastward. Nearly all of the drainage is eastward, with only a few small creeks flowing westward over the prominent composite or fault-line scarp that defines the mountains on the west.

Topographic features of two distinct stages of erosion are present. They consist of relics of a late-mature or broad valley stage that are dissected by deep, narrow canyons of a later stage.

Feature of the late-mature stage are rounded hills, ridges, and spurs and their relative positions - elevation approximately 5500 feet - with respect to the features of the younger canyon stage. A few peaks - Klone Peak, Cougar Mountain and Signal Peak - are present on this surface which has a maximum relief of 2500 feet. The contact between the late-mature and the later canyon stage is characterized by a sharp angle which is a marked feature of the topography.

Relics of the late-mature surface are nearly continuous along the crest of the Entiat Mountains southeastward into

Chelan quadrangle where they have been studied and described by Bailey Willis (1903, 1939) and Waters (1930, 1939). Similar relics have been reported by Page (1939) on Icicle Ridge and the northern slope of Mt. Stuart in the southern half of Chiwaukum quadrangle and by Chappell (1936) in Wenatchee and Malaga quadrangles.

Bailey Willis (1903) considered the relic surfaces to represent two stages - Methow and Entiat - of erosion. The Methow surface was considered to be a peneplain of widespread distribution. It corresponds with the Cascade Peneplain or Cascade Plateau of I. C. Russell (1898-1899). According to Willis, the Methow Plain was later elevated and then eroded to a rolling matureland which he named the Entiat surface. After development of the Entiat surface, renewed elevation gave rise to the deep canyons of the Twisp stage of erosion.

Bailey Willis (1939) later modified the above interpretation. He regarded the surfaces previously referred to as the Methow and Entiat surfaces as belonging to one stage of erosion, the Entiat stage. This later interpretation is in agreement with the work of Waters (1930, 1939), Chappell (1936), Page (1939), and the author.

Although there is agreement among workers as to the presence of a relic late-mature surface, its age is a subject of controversy. Bailey Willis (1903) originally believed it to be post-Yakima basalt (Middle Miocene) in age, but later he

(Bailey Willis, 1939) considered Waters' (1939) interpretation of pre-Yakima basalt in age as being correct. This latter view was also favored by Page (1939). Evidence for this interpretation (Waters, 1939) was the apparent absence of a late-mature surface or broad valley stage of erosion (Entiat stage) on the Yakima basalt, and the apparent projection of the Entiat surface beneath the Yakima basalts in the southern half of Chelan quadrangle. Chappell (1936), on the other hand, considered the late-mature surface to be post-Yakima basalt in age. Evidence for this interpretation is the presence of composite canyons with broad outer valleys and deep, narrow inner canyons developed on the Yakima basalt in Wenatchee and Malaga quadrangles.

The author favors a post-Yakima basalt age for the late-mature surface. Evidence for this interpretation is the presence of composite canyons with broad outer valleys and deep, narrow inner canyons on both the Yakima basalt (Chappell, 1936) and older rocks.

The above interpretation does not imply that the cycle of erosion that gave rise to the late-mature surface is all post-Yakima basalt in age. It is possible that this cycle of erosion had its inception in early Eocene, but it may have been later. However, the surface had reached maturity by the beginning of the outpouring of the Yakima basalts. This is illustrated by the mature character of the surface upon which the basalts rest. The composition of numerous beds of fine and

medium-grained sediments intercalated with the basalt flows suggests that erosion of metamorphic and granitic rocks was taking place during Middle Miocene. In the Waterville area these intercalated sedimentary beds have a mineral assemblage similar to the metamorphic and granitic rocks west and north of the Columbia River (Waters, 1930). Before regional uplift in late Tertiary, possibly late Pliocene or early Pleistocene, erosion had advanced to late-maturity with the development of broad valleys in the Yakima basalts and older rocks.

Swauk Terrain

The Swauk terrain, which is south of Basalt Peak and between the Entiat Mountains to the east and the central mass of the Cascade Mountains to the west is restricted to the area occupied by the Swauk formation. It is sharply defined on the east by a fault-line or composite scarp which is one of the most prominent topographic features in the area. The boundary on the west is less prominent but well defined.

The Swauk terrain differs topographically from the adjacent areas largely because of the difference in lithology - the Swauk formation being less resistant to erosion than the metamorphic and granitic rocks in the adjacent areas. Erosion has gone to maturity with a maximum relief of 2400 feet at Natapoc Mountain. The ridges are narrow and may be parallel or transverse to the structure. It is uncertain that any relies

of the Entiat surface are present, but the surface underlying the Summit conglomerate possibly belongs to the Entiat stage of erosion.

The Wenatchee River is the master stream in the area under consideration. It drains Wenatchee Lake which in turn receives its water from Little Wenatchee and White Rivers. It has a grade of 12 feet to a mile between Wenatchee Lake and the granitic barrier at Tumwater Canyon where the grade increases to 80 feet to a mile. It emerges from Tumwater Canyon at Leavenworth and flows southeastward with a grade of 22 feet to a mile to Wenatchee where it empties into the Columbia River.

The drainage pattern of the Wenatchee River and its tributaries is complex. This complexity is largely due to marginal drainage of valley glaciers and in part to superposition. The latter will be considered first.

It is possible that Wenatchee River had its present course in the vicinity of Tumwater Canyon before the time of broad regional uplift that gave rise to the Cascade Mountains and the Twisp stage of erosion. Its course over the granitic barrier at Tumwater Canyon may have been superposed upon the granitic rocks from a cover of the Swauk formation. During uplift, downcutting was sufficient to maintain its present course. It seems very improbable that the Wenatchee or the Chiwawa River ever by-passed the granitic barrier by flowing

southward in the valley now occupied by Chumstick Creek. It would be extremely difficult to explain the present course of Wenatchee River with such an hypothesis.

Presumably in late Pleistocene, valley glaciers occupied the valleys of White and Little Wenatchee Rivers. They converged in the area now occupied by Lake Wenatchee to form the Wenatchee Glacier (Russell, 1898-1899) which moved eastward to the Entiat Mountains and southward in the Wenatchee Valley. The southernmost advance is not well defined, but the broad, filled valley of the Wenatchee River suggests that the valley was eroded and deepened by glacier action to a position approximately four miles south of Plain.

The presence of the Wenatchee Glacier modified the drainage pattern by giving rise to a complex marginal drainage which is represented by Clear, Deep and Goose Creeks, and possibly by Chumstick Creek, Chiwaukum Coulee, and the lower portion of Chiwawa River between its junctions with Elder Creek and Wenatchee River. Chiwaukum Coulee may have been formed by blocking the lower portion of Nason Valley by the Wenatchee Glacier thus diverting the drainage of Nason Creek southward to Tumwater Canyon. It is possible that Little Chumstick Creek was formed as a marginal drainage channel to the Wenatchee Glacier when it occupied a position of its greatest advance. The close relationship between the upper portion of Chumstick Valley and the valleys of marginal drainage directly to the north

is clearly shown on the topographic sheet. The wind gap between Wenatchee and Chumstick Valleys four miles south of Plain is probably another feature of marginal drainage. As the glacier receded, or possibly at a later advance, it gave rise to the valleys now occupied by Clear, Deep and Goose Creeks. These streams have their headwaters in a valley that runs parallel to the base of the Entiat Mountains. Chiwawa River may have flowed through the area now occupied by Fish Lake prior to glaciation. Its present course between Elder Creek and its junction with Wenatchee River may be due to marginal drainage.

Entiat Scarp

The Entiat scarp, which defines the Entiat Mountains on the west, is one of the most prominent and conspicuous topographic features in Chiwaukum quadrangle. It extends southeastward from Basalt Peak to the Columbia River, a distance of forty miles, and has a maximum height of approximately 3000 feet from its base to its crest. It is rather featureless with only small streams, most of which are intermittent, cutting into its face. The drainage of the Entiat Mountains is dominantly eastward; the divide between the east and west drainage is at the crest of the scarp.

The scarp may be a fault-line or composite scarp; evidence is not conclusive. A fault-line scarp is suggested by

the presence of the relic late-mature surfaces previously described, by the superposed character of Wenatchee River at Tumwater Canyon, and by the relative elevation of Summit conglomerate on Natapoe Mountain which is only slightly lower than some of the relic late-mature surfaces. These suggest that the graben was filled with the Swauk formation before the general uplift of the Cascade Mountains. After uplift the Swauk formation, which is less resistant to erosion than the metamorphic and granitic rocks, was flushed out of the graben to produce a fault-line scarp. However, there is no evidence to show that some movement did not take place during regional uplift.

GEOLOGIC HISTORY

A thick succession of fine and medium-grained clastic sediments along with basic igneous rocks and subordinate quantities of limestone accumulated in a geosynclinal belt which included the area of Chiwaukum quadrangle. The age of the rocks is not known. They may range from early Paleozoic to middle Mesozoic in age.

Presumably in late Jurassic (Nevadian disturbance), the sedimentary and basic igneous rocks were intensely deformed, regionally metamorphosed, and metasomatically migmatized and granitized which gave rise to the rocks of the Metamorphic Complex. Metasomatism was a continuous process that was active during and after deformation. Its maximum development is expressed in the granitic rocks of the Chelan facies.

Granitization was followed by the emplacement of a lamprophyre-granophyre dike complex. The dikes are post-Metamorphic Complex and pre-Swauk in age.

By late Cretaceous time, central Washington was part of a widespread coastal lowland that may have extended southward from British Columbia into Oregon and westward from Idaho to and beyond the present position of the coast. The rocks exposed on this surface were deeply weathered, at least in places, which produced iron ore and clay deposits, the former being derived from basic rocks (Lupher, 1944) and the latter from

acidic rocks of the basement complex.

During Paleocene and possibly beginning in late Cretaceous time, the coastal lowland subsided differentially and received a thick succession of continental sediments, the Swauk formation. In Chiwaukum quadrangle, the total downwarping was sufficient to permit the accumulation of over 12,000 feet of arkosic sediments.

The sediments of the Swauk formation were transported and deposited by large westward flowing streams which built aggradational plains of coalescent sheets and lenses of alluvial detritus. They may have been deposited over a vast area including large portions of central and western Washington. It is possible that they were continuous with deposits in western Washington which may represent, in part, the deltaic deposits of the streams.

The great thickness, areal distribution and mineral composition of the Swauk formation strongly suggests that the sediments were derived from granitic massifs of strong relief that were uplifted northeast or east of Chiwaukum quadrangle during the time of Swauk sedimentation. The areal distribution of the granitic massifs is not known, but it may have included the area of the Okanogan Highlands in northeastern Washington.

After deposition of the Swauk formation, the rocks were folded,¹ faulted, and differentially uplifted into northwest-

¹ Minor folding took place during Swauk sedimentation in the area of Wenatchee quadrangle (Chappell, 1936), but, for the most part, folding was post-deposition.

southeast trending structures. Faulting and differential uplift gave rise to a large, wedge-shaped, northwest-southeast trending graben and placed approximately 12,000 feet of Swauk strata in fault contact with the rocks of the basement complex. The trend of the Entiat Mountains, which are bounded on the west by a major fault, was established at this time.

The deformation was followed by erosion. In the area of Mt. Stuart quadrangle, the folded strata of the Swauk formation were eroded to an uneven surface before the outpouring of the Teanaway basalts in early Eocene time. In the area of Chiwaukum quadrangle, it is possible that erosion has continued to the present time. Post-Swauk sediments and flows, if ever present in Chiwaukum quadrangle have been removed¹ and the record of their presence destroyed.

During early Eocene time (Weaver, 1947) lavas of the Teanaway basalt came to the surface through many fissures and gave rise to several thousand feet of basaltic flows. The flows and dikes are well exposed south of the Mt. Stuart massif. They may be equivalent in age to the diabase sill and dikes in Chiwaukum quadrangle where the latter cuts folded strata of the Swauk formation (Page, 1939) and is present in fault zones. If flows of the Teanaway basalt ever extended into Chiwaukum quadrangle, they have since been removed by erosion.

1 There are a few minor and local exceptions.

During or after faulting but before the broad regional uplift that gave rise to the Cascade Mountains and the Twisp stage of erosion in late Pliocene or early Pleistocene time, an asymmetrical laccolith of hornblende dacite porphyry was emplaced in the Swauk formation at the apex of the fault block at Basalt Peak in Chiwaukum quadrangle. A definite age cannot be given to this event.

After the outpouring of the lavas of the Teanaway basalt, crustal warping formed a new basin of deposition northwest of Yakima where 2000 to 3500 feet of fluviatile and lacustrine sediments, the Roslyn formation, accumulated during Middle to Upper Eocene time. Some of the sediments of the basal beds were derived from the underlying Teanaway basalt, but the sediments, mostly arkosic, of the other beds were derived from foreign sources.

The Roslyn formation or its equivalent is not present and may never have been present in Chiwaukum quadrangle. It is possible that the area of Chiwaukum quadrangle was furnishing sediment to the late Eocene basin during the time of deposition of the Roslyn formation.

After deposition of the Roslyn formation, the strata were folded and eroded before they were covered with Keechelus volcanics presumably of middle Oligocene to lower Miocene in age. This period of deformation and volcanism has not been recognized in Chiwaukum quadrangle.

By middle Miocene time, erosion had produced a mature surface, part of which is preserved beneath the flows of the Yakima basalts of Eastern Washington. It is probable that this mature stage of erosion is of the same cycle of erosion that ultimately produced the Entiat or late mature stage of erosion in post-Miocene time.

During middle Miocene time, a broad basin, which included a large portion of eastern Washington, was flooded with successive flows of basaltic lavas, the Yakima basalt. In Chelan and Wenatchee quadrangles, the flows came, for the most part, from the south (Chappell, 1936) and encroached higher and higher on the sides of the basin. There is no evidence to suggest that they ever extended as far west as Chiwaukum quadrangle or much beyond their present border.

The character of the sediments of the beds intercalated between the flows of the Yakima basalt suggests that the area of Chiwaukum quadrangle and other areas north and west of the basin were furnishing sediments to the basin during middle Miocene time. In southeastern Chelan quadrangle, the beds consist of silt, clay and sand of fluvial, lacustrine, and aeolian origin and have a mineral composition related to the metamorphic and granitic rocks west and north of the area (Waters, 1930).

The outpouring of the basaltic lavas of the Yakima basalt was followed by deposition of the Ellensburg formation

of Upper Miocene¹ age. The Ellensburg formation is well exposed in Ellensburg and Mt. Stuart quadrangles where it consists of 800 to 1600 feet of andesitic sediments - sandstones, shales, and conglomerates - of fluvial origin and a few intercalated basaltic flows.

After the eruptions of the Yakima basalt and before the broad regional uplift that gave rise to the Cascade Mountains and the Twisp stage of erosion, erosion reduced the surface to a broad valley stage, the Entiat stage, over a widespread area that included Chiwaukum, Chelan, Wenatchee and Malaga quadrangles where relics of the surface may be observed today. This surface may have extended across the area now occupied by the high Cascades. Its former presence is indicated, but not with certainty, by the accordance of summit levels which has impressed many observers.

The Entiat surface was developed upon diverse rock types - the Swauk formation, basement complex, and Yakima basalt - which vary greatly in their resistance to erosion. The fault block in Chiwaukum quadrangle was filled with the Swauk formation. Streams passed from one rock type onto another. It is very probable that the Wenatchee River had its present course in the vicinity of Tumwater Canyon during the Entiat cycle of erosion.

1 The Ellensburg formation may be, in part, early Pliocene in age (Weaver, 1945).

Sometime before uplift, hypersthene andesite of Sugarloaf Peak flowed out upon the Entiat surface. It may have been of local origin and distribution.

The Summit conglomerate of Natapoc Mountain may also rest upon the Entiat surface. Its volcanic sediments may be related, in part, to the volcanism that produced the flow at Sugarloaf Peak.

In late Tertiary time, the flows of the Yakima basalt were warped into folds along pre-existent northwest-southeast structural trends. A prominent anticline, the Wenatchee Mountain Uplift, was formed southeast of Mt. Stuart, the highest erosional remanent in the Cascade Mountains. Another anticline, Badger Mountain Uplift, was formed southeast of the Entiat Mountains. These two anticlines are separated by a broad downwarp southeast of the Swauk filled graben in Chiwaukum quadrangle.

In late Pliocene or early Pleistocene time, the area now occupied by the Cascade Mountains was warped into a major, broad upwarp with a north-south trending axis. This structure was superposed on the northwest-southeast structural trends which had their inception in early Tertiary time.

The relative age of the folds in the flows of the Yakima basalt with respect to the main structural trend of the Cascade Mountains is not certain. They may have been earlier, but there is no evidence in northeastern Chiwaukum quadrangle

to demonstrate two stages of uplift. On the other hand, it is possible that the northwest-southeast trending folds were formed contemporaneous with the main trend of the Cascade Mountains.

Erosion was greatly accelerated - the Twisp cycle - by the uplift. Rejuvenated streams cut deep, narrow inner canyons in the broad valleys of the Entiat surface. Sediments of the Swauk formation were flushed out of the graben; a fault-line scarp was produced along the western border of the Entiat Mountains.

During late (?) Pleistocene time, the canyons were occupied by glaciers. According to Page (1939), there were three stages of glaciation in the vicinity of Leavenworth. The drainage patterns were greatly modified by the development of marginal drainage to the glaciers.

After the last stage of glaciation, the streams were active in re-excavating their valleys. This has been accomplished in part.

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VITA

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MAJOR STRUCTURES

Pre-Tertiary Structures

Presumably in late Jurassic, a thick succession of sedimentary and basic igneous rocks were intensely deformed, regionally metamorphosed, and metasomatically migmatized and granitized. The diverse rock types thus produced have been described previously in this paper in the section entitled "Metamorphic Complex." The attitude of the foliation of these rocks will be considered in this section.

The foliation of the crystalline schists of the Metamorphic Complex of the Entiat Mountains in Chiwaukum quadrangle has a strike of approximately 65° west of north and a north-eastward dip that ranges between 25 and 70° . The attitude and pattern of the foliation is illustrated on the geologic map (Plate No. 46) and geologic cross-section (Plate No. 47).

The transitional contact between the granitic rocks of the Chelan facies and the non-granitized schists is transverse to the foliation in vertical section (Plate No. 47) and nearly parallel to the strike of the foliation as illustrated on the geologic map (Plate No. 46). The foliation maintains a common attitude as it passes from the schists into the granitic rocks (Plate No. 47).