STRATIGRAPHY OF THE PUGET GROUP AND KEECHELUS GROUP IN THE ELBE-PACKWOOD AREA OF SOUTHWESTERN WASHINGTON

by

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Date______________________________

A B S T R A C T

The Elbe-Packwood area includes 350 square miles in Lewis, Pierce and Thurston counties, Washington, between west longitude 122°20'-122°40' and north latitude 46°30'-46°50' in the western foothills of the Cascade Mountains.

The rocks are continental in origin and are early Tertiary and late Pliocene(?) in age. The early Tertiary rocks are divided into (1) the middle(?) Eocene Older Volcanics, (2) the upper Eocene Puget Group and (3) the upper Eocene-Oligocene(?) Keechelus Group.

The Older Volcanics are an unknown thickness of andesite flows and pyroclastic rocks. They are tentatively correlated with the Eocene Volcanic Series near Seattle, and with the middle Eocene Northcraft formation in the Centralia-Chehalis area. The Older Volcanics are pre-Puget in age, possibly Middle or lower Upper Eocene, and may be a lower tongue of the Keechelus Group.

The Puget Group crops out in the Tilton River and Nisqually River districts. In the Nisqually River district, the Puget Group intertongues with the lower Keechelus Group. In the Tilton River district, undifferentiated Puget rocks consist of over 9000 feet of sandstone and shale interbedded with volcanic rocks which may be tongues of the Keechelus Group.

The Keechelus Group, ranging in age from upper Eocene to Oligocene(?), consists of at least 10,000 feet, but possibly over 20,000 feet of volcanic breccias, conglomerates, graywackes, pyroclastics and volcanic flows. The clastic rocks are more abundant than the vol-

canic flows, and volcanic breccias of mudflow origin (lahars) are apparently the most abundant rock type of the region. Andesite is the dominant type of flow; dacite and basalt are subordinate in amount. The Keechelus Group is divided into lower, middle and upper based primarily upon general lithology, and is correlated with the Eagle Creek formation exposed near the Columbia River in southern Washington.

The sequence of early Tertiary rocks has been intruded by sills and dikes which are basic to acidic in composition, although basic intrusions are apparently most abundant.

Unconformably overlying the early Tertiary rocks is the Younger Volcanics, a series of nearly flat lying, Pliocene(?) hypersthene basalts, felsites and volcanic breccias. They may be equivalent to the Pliocene(?) Deep Creek Andesite exposed along the Bumping River in the Mt. Aix quadrangle.

Deformation has produced large, gentle northwest trending folds, and northwest and northeast trending minor faults. Dips average 25° to 35°. The major folding episode of the area probably occurred during late Oligocene and/or early Miocene time.

At least two periods of Wisconsin(?) valley glaciation have occurred, somewhat modifying individual stream shapes and histories, but not the regional drainage pattern.

CONTENTS

ILLUSTRATIONS

STRATIGRAPHY OF THE PUGET AND KEECHELUS GROUPS IN THE ELBE-PACKWOOD AREA OF SOUTHWESTERN WASHINGTON

I N T R O D U C T I O N

LOCATION AND ACCESSIBILITY

Approximately 350 square miles have been mapped in parts of the U.S. Geological Survey Eatonville and Mount Rainier 30' quadrangles in Lewis and Thurston counties about 100 miles south of Seattle, Washington between west longitude 122°20'-122°40' and north latitude 46°30'-46°50'. The area is approximately bounded by branches of State Highway 5, and access is easy from the east, north and west by well maintained state highways (pl. I, p. 3).

Numerous logging roads facilitated field mapping, affording fresh outcrops, and greatly increasing the ease of transportation. Any locality may be reached in three to four hours.

A thick forest and soil cover limited mapping to logging roads and logged areas, to a few excellent stream exposures, and to the tops of a few resistant ridges.

RELIEF AND DRAINAGE

The average relief is approximately 3000 feet, increasing from 2500 feet in the western part to 3500 feet in the eastern part of the area. In general, less resistant sedimentary rocks occur in the western, and more resistant volcanic rocks occur in the eastern part of the area.

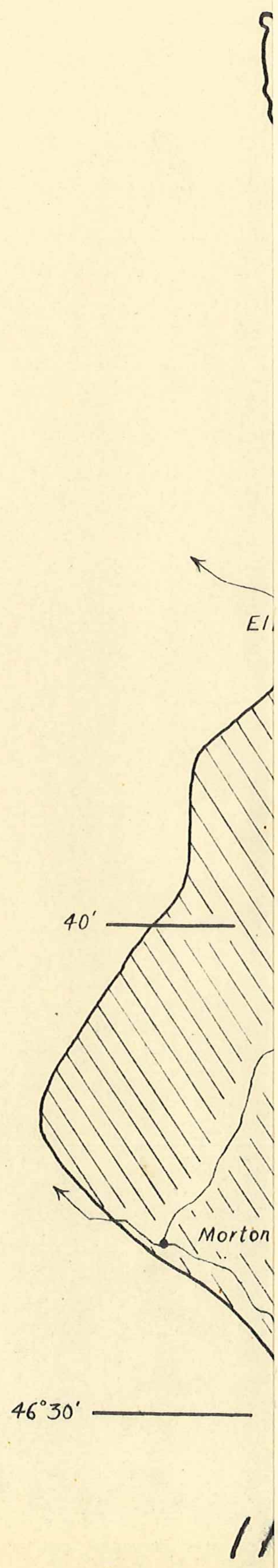
High Rock (5687) is the highest peak, and is located on the southeast end of Sawtooth Ridge from which several other small knobs rise above 5000 feet. Osborne Mountain, Allen Mountain, Skate Mountain and other peaks in the Mount Rainier quadrangle exceed 5000 feet.

Two major river systems drain the area (pl. XXXV, p. 144). On the north, the Nisqually River heads from the Nisqually Glacier on Mount Rainier, and empties into Puget Sound near Tacoma. Its south flowing tributaries are Goat Creek and Copper Creek; its north flowing tributaries are Horse Creek, Berry Creek, Big Creek, Catt Creek, Roundtop Creek and East Creek. On the south is the Cowlitz River, also flowing from Mount Rainier, but emptying into the Columbia River near the town of Castle Rock. The drainage south to the Cowlitz River consists of Skate Creek at the eastern border of the area, Willame Creek, Davis Creek, Silver Creek, Kiona Creek and the Tilton River. The Tilton River drains a large part of the western side of the area with South Fork, East Fork, West Fork and Connelly Creek its main tributaries.

In general, tributaries of the Cowlitz and Nisqually Rivers parallel structural trends. Some streams, however, cross structure, notably Silver Creek, which flows in a deep narrow gorge and empties into the Cowlitz River near Randle. Most streams flow in glaciated valleys and head in dissected cirques or cirque lakes. Waterfalls and rapids are characteristic of all but the large rivers.

Valleys cut in volcanic rocks are narrow and steep-walled; the ridges are narrow and serrated. Valleys underlain by sedimentary rocks are broad with adjacent rounded hills, especially along the Tilton River near Morton.

PLATE I



FIELD WORK

In the summer of 1953, 61 days were spent in mapping. Occasional weekend visits to the area were made during the school year of 1953-54, and, in the summers of 1954 and 1955, 22 additional days were spent checking field data and in detailed mapping of critical areas.

U.S. Geological Survey aerial photographs (scale, 1:47,000) were used for mapping in the Eatonville quadrangle, but photographs of the Mount Rainier quadrangle could not be obtained at the time of field work. Topography for the geologic map was traced from photostatic enlargments of the Eatonville and Mount Rainier quadrangles (scales, 1:125,000). The tracing used for the final geologic map (scale, 1:62,500) has a contour interval of 500 feet. All cross sections were made from the enlarged map.

The rock material is deposited in the Petrography Collection, Department of Geology, University of Washington as Lot No. 6. The fossil material is deposited in the Paleontology Museum, Department of Geology, University of Washington as Lot No. 20.

ACKNOWLEDGMENTS

Appreciation is expressed to the many logging companies that allowed access over private roads, especially St. Regis Paper Company, Skate Creek Logging Company, Harbor Plywood Corperation, Taylor Brothers Logging Company and Ladd Logging Company. The Washington State Forestry Department and the United States Forest Service aided by allowing access to many closed areas.

Discussions of the region with Dr. Howard A. Coombs, University of Washington, and with Leanard Gard of the U.S. Geological Survey are acknowledged. Dr. Roland W. Brown of the U.S National Museum has been extremely helpful in paleobotonical determinations.

Drs. Howard A. Coombs, V.S. Mallory, Peter Misch and Harry E. Wheeler as the thesis committee have all read the manuscript. Dr. Misch as thesis advisor, suggested the problem, supervised the thin section study and has given many hours of valuable assistance. Thanks go to the entire staff of the geology department at the University of Washington for their encouragement. The project could never have been completed without the assistance of my parents and the patience of my wife Beverly.

S T R A T I G R A P H Y

GENERAL STATEMENT

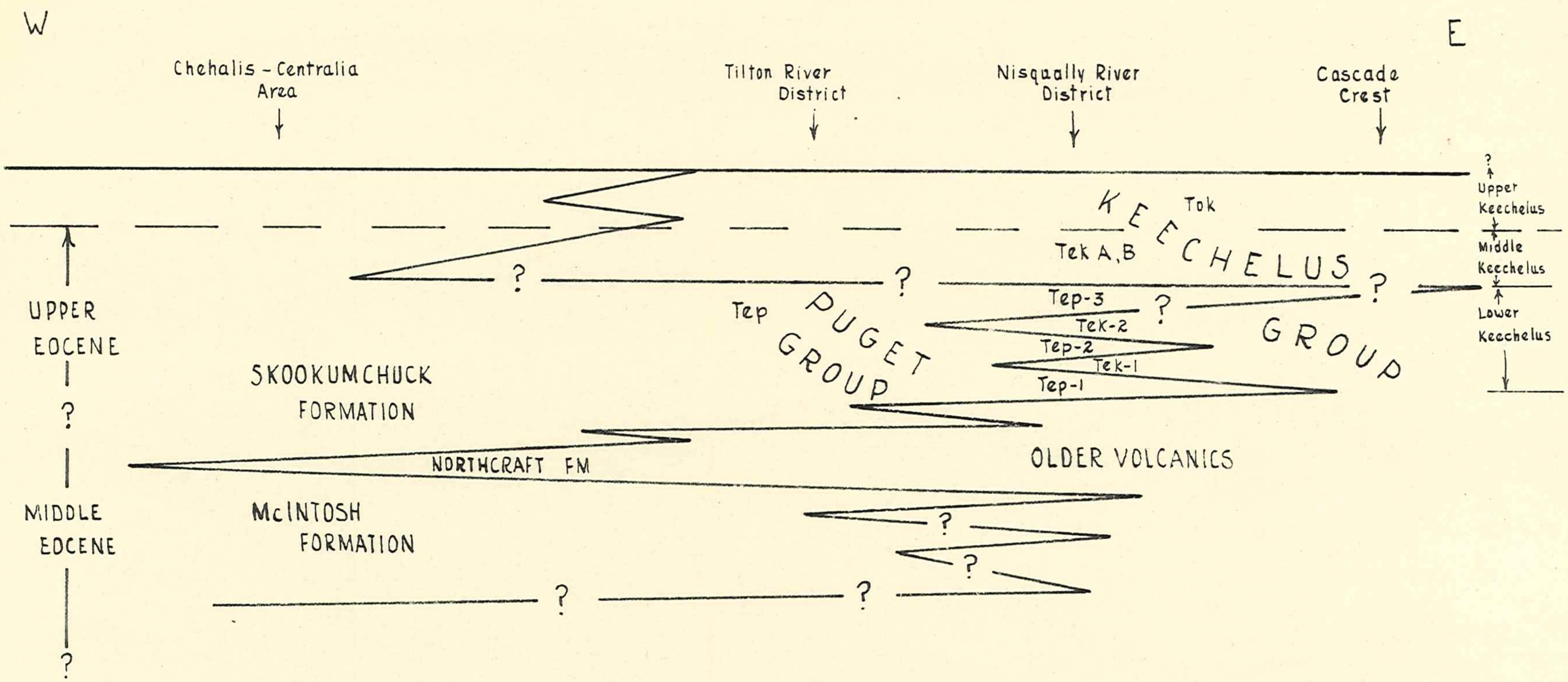
The purpose of this study is to determine the stratigraphic relationships between the upper Eocene Puget Group and the Keechelus volcanics, currently believed to be of Oligocene age. Both groups of rocks are part of an incompletely known, north-south belt of rocks extending in the Cascade Mountains from west-central Washington into southern Oregon. In Washington, the Puget Group crops out in the lowlands and foothills to the west, and the Keechelus Group forms a major portion of the Cascade Mountains to the east.

The Keechelus Group is divided into three parts; lower, middle and upper. The lower Keechelus interfingers with the upper Eocene Puget Group near Ashford (Nisqually River district), and may interfinger in the headwaters of the Tilton River (Tilton River district). This part of the Keechelus is therefore regarded as upper Eocene. The terms middle and upper Keechelus are used for the early Tertiary volcanic rocks which lie stratigraphically above the Puget Group. The middle Keechelus is regarded as upper Eocene on the basis of fossil leaves. The upper Keechelus is regarded as Oligocene, but the fossil leave evidence is not conclusive.

Volcanic rocks that occur stratigraphically below the Puget Group are designated as Older Volcanics, and they may be a lower tongue of the Keechelus Group. Plate II (p. 7) is a graphic representation of the supposed early Tertiary rock relationships.

A sequence of Pliocene(?) volcanic flows and breccias unconformably overlies the early Tertiary rocks.

The correlation chart (pl. III, p. 8) shows the probable age



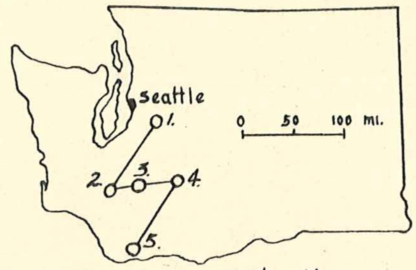
DIAGRAMMATIC STRATIGRAPHIC SECTION OF VOLCANIC AND SEDIMENTARY ROCKS SHOWING POSSIBLE EQUIVALENCE OF PRESENT AREA TO CENTRALIA-CHEHALIS AREA

PLATE II

PLATE III

Correlation Chart

Southern Cascades, Washington



Index Map

Epoch		1. Warren, 1945	2. Snaveley, 1951	3. Present Area 1956	4. Abbot, 1953	5. Feltz, 1939
Pleistocene		Glacial Drift / Hammer Bluff fm	Vashon Drift / Logan Hill fm	Glacial Deposits	Tumac Cinder Cone	Andesite (Pleist.?)
Pliocene				Younger Volcanics	Valley flow Basalt / Deep Creek Andesite	
Miocene		Sedimentary	Basaltic Conglomerate (Miocene?)		Yakima Basalt / Fifes Peak Andesite	Upper Skamania Andesites / Lr. Skamania Andesites
Oligocene		Beds / Keechelus fm	Basaltic sandstone (Oligocene?)	Keechelus Group	Keechelus formation	Eagle Creek formation
Eocene	U	Puget Group / Volcanic Series	Skookumchuck fm	Puget Grp	Puget Group	
	M	Cowlitz fm(?)	Northcraft fm / McIntosh fm	Older Volcanics		
	L					
Paleocene						

relationships of the rocks in the Elbe-Packwood area and the rocks of adjacent areas.

TERMINOLOGY

Pyroclastic

The word pyroclastic is an adjective applied to rocks produced by the aerial ejection of fragmental material from a volcanic vent (Wentworth and Williams, 1932, p. 25). The writer uses the term as strictly defined.

Volcanic Breccia

A volcanic breccia is a pyroclastic rock, an indurated aggregate of fragments larger than 32 mm., composed of rocks which were solidified before their expulsion from a volcanic vent (Wentworth and Williams, 1932, p. 51). However, since breccias composed of volcanic material can originate by processes other than explosive, the writer uses the term _pyroclastic breccia_ for "volcanic breccia" and the term _lahar_ (Cotton, 1944, pp. 239-247) for a "volcanic breccia" transported and deposited by a mudflow. The name "volcanic breccia" is used as a descriptive term for breccias composed of volcanic material but of an unknown mode of deposition.

Volcanic Graywacke

In this report, the term volcanic graywacke is used to describe a dark colored, poorly- to well-sorted sandstone composed predominantly of volcanic fragments. Microscopically a volcanic graywacke is seen to contain about 10% or more argillaceous matrix. A volcanic graywacke can grade vertically or laterally into volcanic conglomerate by an increase in particle rounding and in grain size above 2 mm., or into a volcanic breccia by an increase in particle angularity and in grain size above 32 mm.

Volcanic Conglomerate

A volcanic conglomerate (Wentworth and Williams, 1932, p. 50) is a sedimentary rock containing abundant large, chiefly rounded, water-worn fragments resulting from the erosion and redeposition of volcanic rocks by running water or by mudflows. It is suggested that the lower grade limit be 2 mm., as in sedimentary rock classifications.

Clastic-volcanic Breccia

This term is used by the writer for breccias in which angular volcanic fragments larger than 2 mm. greatly exceed rounded fragments. These breccias originate by erosion and redeposition of volcanic rocks by running water or by mudflows. "Clastic-volcanic rock" is used as a general term for all water transported and deposited volcanic materials.

Tuffaceous Sandstone

This is a rock formed by volcanic particles blown directly from the volcano into the accumulating sediment.

OLDER VOLCANICS

General Statement

Restricted to the Nisqually River district are outcrops of andesite flows and pyroclastic rocks. Exposures are few, about 1% of the area, and are limited to roadcuts along the State Forestry Department fire access road traversing secs. 19 and 20, T15N, R6E. These rocks lie stratigraphically below(?) the Puget Group. They may underlie the Puget Group or may be down-faulted Keechelus rocks. Within the mapped area, the contact between these volcanic rocks and the lowest part of the exposed Puget Group is obscured by glacial deposits, but about five miles north in NE$\frac{1}{4}$ sec. 32, T16N, R6E, volcanic breccias clearly underlie the Puget Group. It is a reasonable assumption that contact relations are the same in the mapped area. Volcanic rocks appear to underlie the Puget rocks in the headwaters of the Tilton River, but reconnaissance mapping does not permit the differentiation of rock units in the Tilton River district.

Lithology

Six specimens from the Older Volcanics were studied. Significantly the mineral epidote (often megascopic) occurs in all except a tuff-agglomerate in sec. 19, T15N, R6E. However, there is no single criterion to distinguish these rocks from those of the Keechelus formation.

The andesites are various shades of gray and greenish-gray, are usually porphyritic, and show little alteration megascopically. The tuff-agglomerate has a gray matrix containing green porphyritic, and light gray, fine-grained volcanic fragments which grade in particle size from tuff through lapilli-tuff to agglomerate.

Petrographic Description

Specimen 1: Porphyritic andesite from NW$\frac{1}{4}$ sec. 19, T15N, R6E in road cut along State Forestry Department fire access road.

Megascopic: Gray to green-gray, contains abundant anhedral to euhedral, microscopic to 1 mm. plagioclase phenocrysts and minor amounts of anhedral pyroxene(?) and epidote grains.

Microscopic: Matrix (60%) is composed of green-tinted, very fine-grained, weakly birefringent, unidentifiable minerals. Plagioclase (25%) has a composition of less than An 50 and is partly altered to kaolin and some quartz. Chlorite (4%) occurs mainly in the matrix in extremely finely divided form, causing a greenish tint, and as a few discrete grains. Epidote (4%) is altered from pyroxene(?). Antigorite (3%) also has altered from pyroxene(?) and is intergrown with some feldspar crystals. Magnetite (2%) occurs as a fine dust in the matrix, and as rims around some feldspar and epidote grains. Kaolin (1%) occurs as an alteration product of feldspar along feather fractures and cracks. Quartz (1%) is present as a secondary mineral in altered plagioclase crystals.

Specimen 2: Tuff-agglomerate from SW¼ sec. 20, T15N, R6E in road cut along State Forestry Department fire access road.

Megascopic: Green, angular and irregularly shaped andesite(?) fragments as much as 35 mm. in size are contained in a gray matrix.

Microscopic: Matrix (15%) is brownish, tuffaceous(?), and contains tiny indeterminate crystals.

Rock fragments (75%) are angular; some grade imperceptably into the matrix material, and some have well defined borders. They are andesitic(?) in composition. A faint alignment around some fragments suggests compaction and agglutination. There are two main rock types among the fragments: one type has a pilotaxitic and felty texture, is very high in plagioclase (50-75%), with recrystallized glass matrix and abundant opaque (magnetite ?) dust throughout, and averages about 0.1% epidote. The second type of fragments have ragged borders and in places grade into the matrix. One such fragment contains plagioclase (10%), magnetite (5%) as an alteration product of pyroxene(?), and apatite (0.1%). The matrix of this second type is 85% of the entire fragment, is very fine-grained, brown in color and contains unidentified, weakly birefringent mineral specks. This second type has highly irregular internal flow structures. Some fragments have very irregular borders (pl. IV, p. 13), suggesting a pyroclastic origin (p. 71).

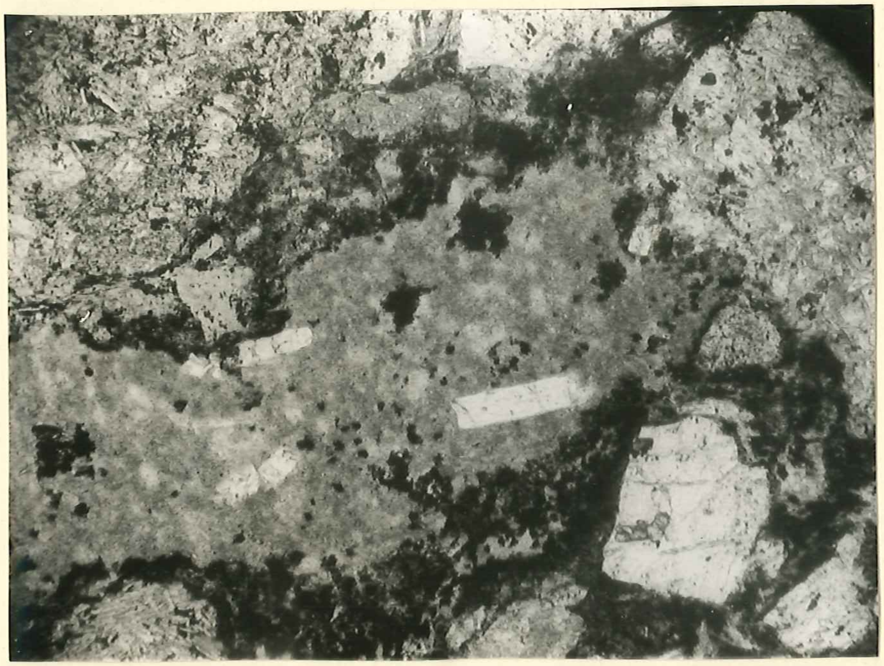
Mineral fragments (10%) are mainly plagioclase with a composition of less than An 50. Some of the plagioclase grains contain included epidote as an alteration product.

Age and Correlation

The Older Volcanics appear to be older than the Puget Group, possibly lower Upper or upper Middle Eocene in age, but a positive age determination is not possible.

They are tentatively correlated with the Eocene Volcanic Series (Warren, 1945) which crops out east of Seattle near Issaquah, north of the present area. According to Warren this series is 7000 feet thick, underlies the Puget Group, and overlies the marine Cowlitz(?) formation (upper Eocene). Fossils in the upper part of the Cowlitz(?)

PLATE IV



Specimen 2: Pyroclastic breccia, Older Volcanics; highly irregular borders of andesite fragment. X240, plain light.

formation indicate an upper Eocene age.

The Older Volcanics are believed to be equivalent to the Northcraft formation exposed in the Centralia-Chehalis area to the west of the present area (Snavely, et al., 1951), because the Skookumchuck formation, which overlies the Northcraft formation, seems to be equivalent to the Puget Group (pp. 58-59).

PUGET GROUP AND LOWER KEECHELUS GROUP

General Statement

The Puget Group consists of a series of upper Eocene continental and estuarine sandstones and shales estimated to be 10,000 to 14,000 feet thick (Weaver, 1937, p. 54). The sandstones are gray and buff to dark brown in color, commonly arkosic in composition and usually contain muscovite. They are massive to thin-bedded, interbedded with shale, and may be cross bedded or show ripple marks. The shales are black, gray, and brown to yellow in color. They are hard to soft, massive to fissile, boney, hackly, and contain concretions, fresh water pelecypods and leaf impressions. In places coal seams are found.

The Puget Group includes 20% of the surface exposures in the Elbe-Packwwod area, and occurs in two districts, each of which is discussed under separate headings. One area of Puget exposures (Nisqually River district) occurs along the Nisqually River near Ashford. The other area of Puget rock exposures (Tilton River district) is in the Tilton River drainage basin between Mineral and Morton.

The Puget Group exposed in the Nisqually River district is at the southern end of a north-south trending belt of sedimentary rocks which crops out discontinuously from Seattle southward. In the Nisqually River district, the Puget Group interfingers with the lower part of the Keechelus Group. Along the north side of the Nisqually River the Puget and Keechelus tongues dip homoclinally eastward on the northeast flank of a large, northwest trending anticline (pls. V and VI, pp. 18-19).

The Puget Group in the headwaters of the Tilton River is lithologically similar to the Puget Group of the Nisqually River district, but contains more interbedded flows. The Puget rocks of this district appear to form a small, south plunging anticlinorium.

Previous Work

Bailey Willis (1880, pp. 759-771), whose chief interest was the coal bearing deposits north of the mapped area, was the first to study the geology of the western side of the Cascade Mountains. He mapped southward within the Puget Group almost to the Nisqually River, although he did not describe any sections south of the Carbon River.

In 1914, Daniels (pp. 23-51) discussed the coal deposits and prospects of Pierce County in almost the same area worked by Willis, and extended the Puget Group south to the Nisqually River.

H.E. Culver briefly described the Puget Group south of the Nisqually River, and the economically more important area of sedimentary rocks in the Tilton River district (1919, pls. XX and XXII, pp. 108-119). He correlated these rocks with the Puget Group on the basis of lithology.

J.H. Mackin published on the geology of the Morton Cinnabar district, 1½ to 2 miles east of the town of Morton (1944, pp. 5-47).

Nisqually River District

Intertonguing units of the Puget and Keechelus Groups which total approximately 8750 feet in thickness, crop out on the north side of the Nisqually River near Ashford (pls. V and VI, pp. 18-19). The Keechelus tongues apparently thin northward, a conclusion supported by observations of the writer and Leanard Gard of the U.S. Geological Survey which indicate that there are no volcanic tongues in the Puget Group along the Puyallup River, eight miles to the north. Further supporting evidence is that no volcanic rocks occur in a well exposed easterly-dipping, 8000 foot section of the Puget Group along the Mowich Lake Road, 13 miles north of the area (Gard, oral communication, 1955). The Puget tongues appear to thin rapidly southward; north of the river they aggregate 6500 feet in thickness, whereas south of the river, only 1000 feet of the upper tongue of the Puget Group is exposed.

The best exposures in the Nisqually River district are on the north side of the Nisqually River (Ashford-Goat Creek section) where the intertonguing units occur as part of the northeast flank of the large, southeast plunging Skate Creek anticline. Many excellent outcrops occur in the Copper Creek drainage basin and in several other small streams from Goat Creek to the vicinity of Ashford. The only outcrop along State Highway 5 is a few yards west of Goat Creek.

On the south side of the Nisqually River (Osborne Mountain subarea), exposures are limited to a northwest trending ridge in sec. 32, T15N, R7E and sec. 4, T14N, R7E; and on the north-facing slope of Osborne Mountain along the Cowlitz-Nisqually trail. Outcrops of light gray sandstone on this slope can be seen from State Highway 5.

Ashford-Goat Creek Section

Eastward dipping units of the Puget Group and lower Keechelus Group occur on the north side of the Nisqually River from about one mile west of Ashford to the vicinity of Goat Creek, a distance of six miles. The intertonguing section is approximately 8750 feet thick as measure in cross section. The Puget rocks total about 6500 feet, and the Keechelus rocks total about 3300 feet in thickness (pl. VI, p. 19).

There are five tongues which are designated as follows:

5. Third Puget Tongue

4. Second Keechelus Tongue

3. Second Puget Tongue

2. Lower Keechelus Tongue

1. Lower Puget Tongue

These units are described in ascending order, beginning with the lower Puget tongue.

Lower Puget Tongue

This unit is composed of more than 3150 feet of interbedded sandstones and shales. The thickness is doubtful because the lower contact is not exposed.

Contacts

The contact of this tongue with the underlying Older Volcanics is drawn in the position shown on the map (pl. V, p. 18) because of a single andesite outcrop a few yards downslope from a Puget sandstone exposure in NW$\frac{1}{4}$ sec. 21, T15N, R6E. It is not known whether the andesite is an interbedded flow, sill, dike or the top of the underlying Older Volcanics. It is assumed to be the latter because (1) volcanic rocks are the only rock types found west of and stratigraphically below the andesite outcrop and (2) the presumed contact is almost exactly on strike with the contact between the Older Volcanics and the Puget Group which is exposed about five miles due north of the locality under discussion.

The contact of the lower Puget tongue with the overlying Keechelus tongue can be located within a few feet in the field, and can be traced on aerial photographs. The two tongues are conformable.

Lithology

The rocks are friable to well-indurated, massive to well-bedded, medium to fine-grained, light and dark gray to brown muscovite-bearing arkose and sandstone with interbedded shale. Many of the sandstones show cross bedding, and some are ripple marked (pl. VII, fig. 2, p. 21). Plant fragments are locally abundant; one outcrop of sandstone contains rounded shale fragments. Interbedded silty shales, from one inch to several feet thick, are friable to fairly well-indurated, fissile (pl. VII, fig. 1, p. 21) to massive and conchoidally fractured, medium gray to black and brown in color, and contain muscovite. Some shales contain leaf fossils, and in one massive, brown, conchoidally-fractured shale outcrop, poorly preserved brackish(?) water pelecypods were found. Thin lignitic to bituminous coal seams occur within the sequence.

Toward the upper contact, the sandstone becomes dark gray to black. The change upward from the sedimentary rocks of the lower Puget tongue to the coarse volcanic graywackes and volcanic conglomerates of

PLATE VII

Figure 1. Outcrop of fissile shale near the base of the lower Puget tongue. Attitude of shale is N5E 25SE.

Figure 2. Translation ripple marks in lower Puget tongue. Attitude of sandstone is N20E 40SE. Ripple marks are at right angles to the dip, and assymetry indicates water flowed to the northwest.

the lower Keechelus tongue is rapid with little or no mixing of rock types. There may be some mixing at the immediate contact, but the immediate contact is not exposed.

Petrographic Description

Specimen 3: Sandstone from NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 22, T15N, R6E about one mile northwest of Ashford.

Megascopic: Medium gray to buff, well sorted sandstone containing some carbonaceous fragments.

Microscopic: The average grain size is 0.08 mm., about 30% is quartz grains and 1% is plagioclase (An 27 to An 29). Staining revealed 5% potassium feldspar. Biotite and muscovite are 5% each. The biotite is disseminated throughout the rock, and in part is slightly altered to a very pale green chlorite (1%). In places the biotite is bent around resistant quartz and feldspar grains. The matrix was lost during preparation of the thin section.

Specimen 4: Sandstone from SE$\frac{1}{4}$ sec. 22, T15N, R6E, about $\frac{1}{2}$ mile northeast of Ashford near the upper contact of the lower Puget tongue.

Megascopic: Medium to dark gray with slight brownish tinge, well-sorted, fine-grained sandstone.

Microscopic: Average grain size is 0.10 mm., about 35% is quartz (some strained) and 5% is plagioclase (An 26 to An 29). Many plagioclase grains appear to have been altered to sericite before deposition. Staining revealed 1% potassium feldspar. Biotite comprises 10% of the rock, some altered to chlorite, and many of the grains are bent around more resistant grains. Muscovite is 10%, and like the biotite it has been bent (pl. VIII, p. 23). Chlorite is 5% and is mainly altered from biotite, although some appears to be primary(?). There is 2% cherty-looking fragments, and about 0.1% opaque minerals (magnetite?). The matrix (30%) consists of dirty brown, clay-size material and secondary calcite.

Lower Keechelus Tongue

This unit is about 1800 feet thick, and is the lowest tongue of the Keechelus formation exposed in the Ashford-Goat Creek section.

PLATE VIII

Specimen 4: Sandstone, Puget Group. Note bent muscovite grain and strained quartz particle in center of photograph. X 240, crossed nicols.

Contacts

The lower contact of this tongue can be seen in two places from State Highway 5; on the steep valley slope north of Ashford, and on the steep valley slope about one mile east of Ashford in S½ sec. 23, and N½ sec. 26, T15N, R6E (pl. IX, p. 25).

The upper contact is not exposed, but on the basis of muscovite-bearing arkose found in E½ sec. 25, T15N, R6E at the base of the ridge, the contact was placed slightly southwest of the ridge crest. It strikes to the northwest.

Coarse-grained rocks occur near the base, and grade upward to finer-grained rocks toward the top of the unit.

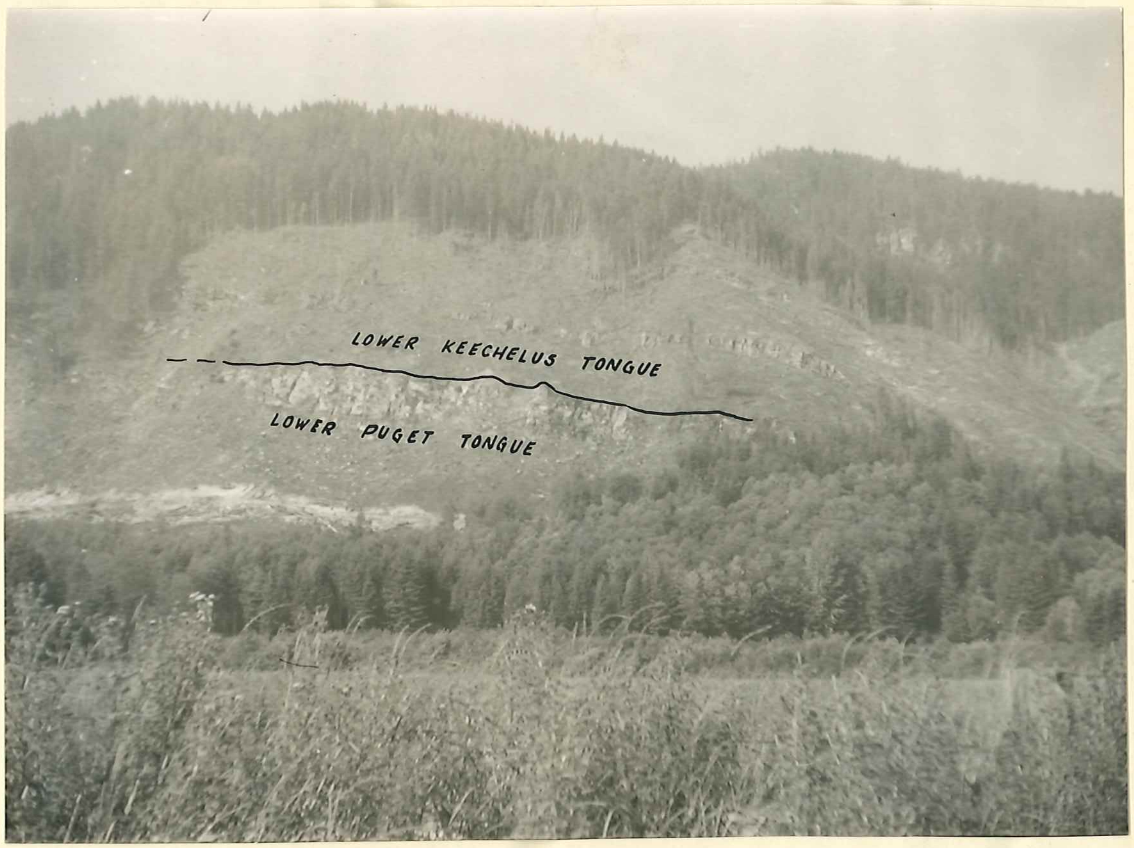
Lithology

The rocks are well indurated, massive, medium gray, gray-green, green-brown, and brown clastic-volcanic breccias and volcanic graywackes. Only one andesite flow was found.

The clastic-volcanic breccias contain angular to well-rounded cobbles as much as 4 inches in size, most of which are angular to subangular, black, gray, green or red andesite porphyries. None of the observed fragments are vesicular. The matrix is volcanic graywacke with a few disseminated carbonaceous fragments.

The interbedded volcanic graywacke is medium- to fine-grained and is often difficult to distinguish from flows, but the fragmentary shapes of the feldspars, occasional andesite pebbles, and faint lamination planes distinguish them. They are dark green to medium gray-green in color and usually very well indurated.

PLATE IX



Contact between the lower Puget tongue and lower Keechelus tongue. View is north from State Highway 5. Outcrop is in N½ sec. 26, T15N, R6E.

The flow is a slightly porphyritic andesite that weathers to a reddish-buff color, and is found in SE¼ SW¼ sec. 23, T15N, R6E at the contact between the lower Puget tongue and the lower Keechelus tongue.

Petrographic Description

Specimen 8: Graywacke matrix of a clastic-volcanic breccia from near the lower contact of the lower Keechelus tongue in SW¼ sec. 23, T15N, R6E.

Megascopic: Medium green-gray in color, well indurated, fairly well sorted, with medium to fine-grained fragments.

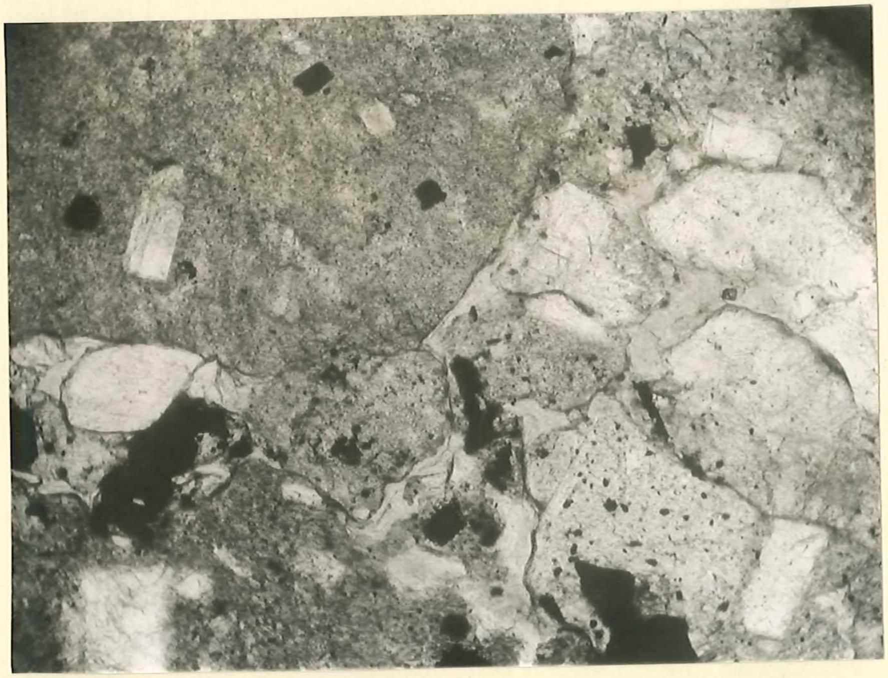
Microscopic: Fragments are rounded (pl. X, p. 27) to angular in shape and are usually surrounded by matrix material, although some touch and have a somewhat agglutinated appearance. This squeezing together is the result of later compaction. The matrix comprises about 15% of the rock and is a dirty brownish color. It contains rock and mineral fragments of 0.0004 mm. in size and probably smaller. There are many very tiny felty feldspar laths and some possibly devitrified glass fragments. Under crossed nicols with the low power objective lens, the matrix looks somewhat isotropic because it is so fine grained. There are all gradations from the smallest particle of the matrix to a maximum of 0.8 mm. Plagioclase grains (An24 to An 30) are 30% of the rock and are mainly fragments of larger crystals. Some plagioclase grains have centers altered to calcite. Chlorite is 15% and sometimes is rimmed with magnetite. It is mainly a secondary mineral altered from pyroxene(?). Magnetite is 5% and occurs as disseminated grains and as alteration rims around chlorite. Calcite is 5% and is the result of alteration from some of the plagioclase grains. There are 4 to 5 different types of andesite rock fragments comprising 30% of the rock. They appear to be somewhat similar in composition but are different in texture, color and percentage of phenocrysts.

Specimen 9: A rounded andesite cobble of the clastic-volcanic breccia from near the lower contact of the lower Keechelus tongue in SW¼ sec. 23, T15N, R6E.

Megascopic: The rock is a gray porphyritic andesite.

Microscopic: The matrix is composed of a brownish glass, devitrified to a low birefringent, very

PLATE X



Specimen 8: Graywacke matrix of clastic-volcanic breccia, lower Keechelus tongue. Photograph shows rounding of andesite and plagioclase fragments. X 320, plain light.

fine-grained indeterminate mineral or minerals. Plagioclase (An 39) has a ragged appearance with obscure twinning planes. Chlorite has altered from pyroxene(?). Magnetite, closely associated with chlorite, is an alteration product of ferro-magnesian minerals. There has been considerable alteration of the rock to chlorite, magnetite and calcite.

Specimen 10: Volcanic graywacke from near the lower contact of the lower Keechelus tongue in SW$\frac{1}{4}$ sec. 23, T15N, R6E, stratigraphically slightly above specimens 8 and 9. The specimen is from a highly fractured zone.

Megascopic: The rock is medium olive-green in color, contains abundant small milky plagioclase crystals. On first appearance the rock looks like a highly porphyritic flow, but occasional faint laminations due to slight changes in grain sizes, or in feldspar concentrations, indicate its sedimentary origin.

Microscopic: Plagioclase grains (30%) are fragments of larger crystals, and are untwinned except for one small crystal (An 38). The plagioclase has largely been altered to kaolin. There are small bits of hornblende (2%) and augite (5%) scattered throughout the rock. Most of the ferro-magnesian crystals have been altered to chloritic substances. The matrix comprises about 60% of the rock and is a mixture of devitrified glass fragments, poorly developed and irregularly-shaped plagioclase fragments, chloritic matter and small rock and crystal fragments which were not identified.

Second Puget Tongue

This unit, about 650 feet thick as measured in cross section, trends northwest and dips about 30° eastward. It crops out in a small unnamed creek in sec. 24 and 25, T15N, R6E. The tongue appears to thin southeastward.

Contacts

The lower contact is not exposed, but was placed in the position shown on the map (pl. V, p. 18) for reasons stated on page 24.

The upper contact of this Puget tongue appears to be conformable and transitional with the overlying Keechelus tongue, but the relationship is somewhat obscured by minor faulting and landsliding in secs. 24 and 25, T15N, R6E. Toward the upper contact, the sandstone becomes fine-grained and dark gray, and the interbedded shales become black in color. Above the contact, black friable shale is found interbedded(?) with volcanic conglomerate and breccia, but upward, the section soon becomes entirely volcanic.

Lithology

The rocks, similar to those of the lower Puget tongue, are massive and well-bedded, well- to fairly well-sorted, medium- to fine-grained, light to dark gray and brown, muscovite-bearing sandstones interbedded with gray to black and brown, massive to fissile shales. Cross laminations are found in some of the sandstones (pl. XI, p. 30), and one outcrop of black, well indurated shale shows well developed spheroidal weathering (pl. XI, fig. 1, p. 30). Carbonaceous fragments and poorly preserved leaf fragments are found along bedding planes in the shales and in the fine-grained sandstones.

Petrographic Description

Specimen 11: Impure muscovite-bearing sandstone from near the upper contact of the second Puget tongue in NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25, T15N, R6E. The specimen was collected from a sequence of interbedded black to dark gray, well-indurated shales and light to dark gray, fine-grained sandstones.

Megascopic: The rock is well-indurated, well-sorted, fine-grained, medium to dark gray in color and has wavy lamination planes.

Microscopic: The rock contains 25% angular quartz grains and 9% plagioclase grains (An 27 to An 30). It contains 10% carbonaceous fragments and 5% chert grains. Biotite and muscovite are 5% each, with some grains bent around the more resistant quartz and feldspar grains. Chlorite (1%) is pennine, and like the mica, has been bent around resistant grains. The matrix (40%) is a very fine-grained

PLATE XI

Figure 1. Spheroidally weathered black shale near the upper contact of the second Puget tongue.

Figure 2. Cross laminations in light gray muscovite-bearing sandstone of the second Puget tongue.

silt mixed with dirty brown argillaceous and organic matter.

Specimen 12: Impure muscovite-bearing sandstone from near the upper part of the second Puget tongue in SW$\frac{1}{4}$ sec. 24, T15N, R6E. It was collected from a sequence of interbedded dark gray siltstone and shale.

Megascopic: The rock is well sorted, fine- to medium-grained, and is medium gray to gray-brown in color. It is well indurated.

Microscopic: The rock contains 25% quartz (much is strained) and 8% plagioclase (An 26 to An 27). It contains 15% biotite and 5% muscovite, both of which have been bent around more resistant grains. Chert is 5% and magnetite is 2%. One grain of corundum was observed. The matrix (40%) is composed of calcite.

Specimen 13: Muscovite-bearing arkose from near the middle of the second Puget tongue in S$\frac{1}{2}$ NE$\frac{1}{4}$ sec. 25, T15N, R6E. The rock was collected from a massive sandstone outcrop with abundant carbonaceous fragments.

Megascopic: The rock is well-indurated, light to medium gray in color, coarse- to medium-grained, and is fairly well sorted.

Microscopic: The rock contains 35% angular quartz grains some of which are strained and some of which are derived from vein quartz. There is 20% angular, somewhat kaolinized plagioclase grains (An 29 to An 35). Staining shows 5% potassium feldspar. Biotite is 15% and muscovite is 4%; both have been bent around resistant mineral grains. There is 10% chert and quartzite fragments, 5% secondary calcite, and 1% leucoxene. Chlorite (0.1%) is an alteration product of biotite. Two sandstone granules and a possible volcanic fragment were observed. The matrix (5%) is argillaceous, and is stained by iron oxide. The mineral grains average 0.06 mm., and vary from 0.08 mm. to submicroscopic in size.

Second Keechelus Tongue

This unit is about 1500 feet thick, trends northwest, and is lithologically very similar to the lower Keechelus tongue.

Contacts

The lower contact is described on page 29.

The upper contact, exposed in SW$\frac{1}{4}$ sec. 19, T15N, R7E, trends N10W, dips 20° eastward, and is conformable with the overlying Puget tongue.

Lithology

The rocks are volcanic conglomerates, clastic-volcanic breccias, volcanic graywackes and tuffaceous(?) sandstones. One outcrop of medium-gray porphyritic andesite was observed near the lower contact. Two outcrops of flow(?) rocks are exposed near the top of the sequence, one a light gray-green andesite with a few milky plagioclase phenocrysts as much as 3 mm. long; the other a very fine-grained black basalt. The prevailing colors of the rocks are gray and gray-green, and the weathering colors are medium brown to buff.

The sequence begins with a volcanic pebble conglomerate and is succeeded upward by volcanic breccias, conglomerates and graywackes. At the top of the unit is a medium- to fine-grained well bedded volcanic graywacke in contact with muscovite-bearing sandstone and shale of the overlying Puget tongue.

Petrographic Description

Specimen 14: Volcanic pebble conglomerate from near the lower contact of the second Keechelus tongue in NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25, T15N, R6E. The specimen is from an outcrop of pebbly conglomerate to coarse sandstone with occasional cobbles up to 4 inches in size.

Megascopic: The rock is very well indurated, is gray-brown to olive greenish-brown in color, and contains scattered carbonized wood fragments. Most of the grains are angular to subangular in shape, and are composed of olive green, gray and black andesite porphyry fragments.

Microscopic: The rock contains 85% rock and mineral fragments and 15% matrix. The matrix is a dirty brown argillaceous(?) material with minute fragments 0.0004 mm. and less in size. In places there are secondary calcite grains.

Angular quartz grains comprise about 1%, and untwinned plagioclase grains about 20% of the rock. There are 3% carbonized wood fragments. Most of the andesite fragments (about 20% of the rock) have been completely altered to calcite. Some of the andesite fragments are fresh and very well rounded, but most are angular to subangular in shape, and usually have very irregular borders.

Microscopically the rock appears to be pyroclastic in origin, except that some rock fragments are very well rounded. Field relations indicate a sedimentary mode of deposition.

Specimen 15: Tuffaceous sandstone from NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25, T15N, R6E, about 400 feet stratigraphically above the lower contact of the second Keechelus tongue.

Megascopic: The rock is poorly sorted, is dark gray, and contains conspicuous light olive green andesite fragments. One black vesicular fragment was observed in the hand specimen.

Microscopic: The matrix (50%) is dark brown to black in color and is opaque. It appears to be composed of glassy material heavily charged with dust-sized mineral grains.

The rock contains 20% primary quartz grains, 5% untwinned plagioclase and 2% chert fragments. Andesite fragments compose 20% of the rock, and may be almost all partially altered to chloritic material. Many of the rock fragments show vesicles. Some contain secondary quartz growths between mineral grains. All the fragments are angular.

Third Puget Tongue

This unit, about 1900 feet thick, trends north to northwest and appears to thin southward. It crops out extensively in the Copper Creek drainage basin, and has an outcrop width of about two miles due to repetition in a minor anticline and syncline.

Contacts

The upper and lower contacts diverge slightly to the north, suggesting thickening of the unit in that direction, although the widening of the outcrop area may be entirely due to the folding mentioned above.

The lower contact is described on pages 31-32.

The immediate upper contact is not exposed, but the overlying

Keechelus rocks appear to be conformable on the Puget rocks. This contact extends continuously to the Puyallup River, approximately eight miles to the north (Willis, 1880, geologic map).

Lithology

Lithologically this tongue is similar to the lower and second Puget tongues, displaying a rather monotonous sequence of muscovite-bearing, gray and brown colored, well sorted sandstone and arkose interbedded with gray and black shale and thin coaly layers. Leaf fossils were collected in two localities near the middle of the unit (pp. 54-55).

Petrographic Description

Specimen 16: Sandstone from NE$\frac{1}{4}$ sec. 30, T15N, R7E. The specimen was collected from an outcrop of interbedded sandstone and dark gray to black friable shale containing fossil leaves and thin coaly layers.

Megascopic: The rock is light to medium gray, fine-grained, well sorted, and is fairly well indurated. It contains discontinuous and wavy lamination planes.

Microscopic: The rock is well sorted with grains that average about 0.12 mm. in size. Lamination planes are caused by concentrations of sub-parallel biotite flakes. The matrix (35%) is composed of very fine-grained clastic fragments with little or no admixed argillaceous material. Quartz grains are 35% of the rock, many of which have highly irregular borders. Plagioclase grains (An 24 to An 34) are 10% of the rock, are angular in shape, and have been altered slightly to calcite. Muscovite and biotite grains are 5% each, and both have been squeezed and bent around resistant grains. Most of the biotite has been bleached and altered, and grades into chlorite and into muscovite(?). Chlorite and calcite grains are 5% each. The chlorite has altered from biotite, and the calcite has altered from plagioclase grains. Magnetite is about 0.1% of the rock and has formed mainly by the breakdown of biotite.

Osborne Mountain Subarea

The third Puget and second Keechelus tongues are exposed in limited outcrops along the south side of the Nisqually River, and are continuations of those tongues from north of the river.

In SE$\frac{1}{4}$ sec. 32, T15N, R7E, and NE$\frac{1}{4}$ sec. 4, T14N, R7E are outcrops of Puget arkose with some interbedded shale that are underlaid by tough, gray-green snad green andesite flows. The arkose and shale, estimated to be 1000 feet thick, is correlated with the third Puget tongue on the basis of lithology and attitude. The underlying andesite is correlated with the second Keechelus tongue because of its stratigraphic position below the third Puget tongue, although north of the river in SW$\frac{1}{4}$ sec. 19, T15N, R7E, the uppermost part of this Keechelus tongue is a fine-grained, well bedded volcanic graywacke. This difference in lithology of the Keechelus tongue probably represents a facies change.

The rocks in the Osborne Mountain subarea are folded across the nose of a large, southeast plunging anticline. The surface trace of the Puget tongue therefore bends at almost 45°, changing its strike from about north-south to east-west. Arkose on the south side of the fold in secs. 6 and 7, T14N, R7E, half way up the north side of Osborne Mountain, is correlated with the arkose on the northeast side of the fold in NE$\frac{1}{4}$ sec. 4, T14N, R7E on the basis of similar lithology, and because the arkose in both places are overlaid by the middle Keechelus Group (Tek A, pl. XXXVI, p. 154).

Contacts

The contact of the third Puget tongue with the overlying middle Keechelus Group is not exposed, but similar attitudes in both groups indicate that they are conformable. On Osborne Mountain, the arkose appears to be directly overlaid by a Keechelus volcanic pebble conglomerate which grades upward into coarse-grained volcanic breccias. The arkose in NE¼ sec. 4, T14N, R7E is overlaid by Keechelus volcanic graywackes and breccias, but the contact between the two formations at this place is covered.

No arkose could be found along the Nisqually River west of Osborne Mountain, but because of the structural trends in the overlying Keechelus rocks, the arkose is assumed to extend northwest beneath the Nisqually River valley. It may thin out in that direction or, as shown on the geologic map (pl. XXXVI, p. 154), it may be cut out by the Catt Creek fault.

Lithology

The arkose exposed in SE¼ sec. 32, T15N, R7E, in NE¼ sec. 4, T14N, R7E and on Osborne Mountain are lithologically very similar. They are light gray, medium- to coarse-grained, well sorted, fairly well indurated arkoses with conspicuous muscovite flakes and occasional thin carbonaceous bands. In SE¼ sec. 32, T15N, R7E the sandstone is underlaid by gray silty shales containing fossil leaves (upper Eocene?). These shales are interbedded with gray and buff colored sandstones and black lignitic coal layers.

In both NE¼ sec. 4, T14N, R7E and SE¼ sec. 32, T15N, R7E, the sedimentary rocks are directly underlaid by tough, gray-green to green, porphyritic andesite.

Petrographic Description

Specimen 17: Arkose from NE¼ sec. 4, T14N, R7E, from an outcrop south of the Nisqually River along Skate Creek Logging Company logging road. This specimen is from the third Puget tongue.

<u>Megascopic</u>: Light gray rock with some small dark reddish-brown weathering spots, well sorted, medium-grained, and fairly well indurated.

<u>Microscopic</u>: The matrix (5%) is composed of quartz and feldspar grains averaging about 0.04 mm. in size, and is restricted to pockets between the larger clastic grains. Quartz grains (30%) are mostly strained, and some have a metamorphic pavement texture (pl. XII, p. 38). Plagioclase grains (10%) vary in composition from An 26 to An 34. Orthoclase, microcline and perthite are about 15% of the rock. Biotite (0.1%) is largely altered to a pale brown mineral. Muscovite grains (2%) are generally oriented parallel to the bedding planes of the rock. Chert fragments are 10% of the rock. One possibly volcanic fragment was observed. All the mineral grains are angular in shape, and average about 0.4 mm. in size.

Arkose from an outcrop slightly higher in the section is somewhat similar to specimen 17, but the feldspar grains are more kaolinized, and the rock contains some secondary calcite.

<u>Specimen 18</u>: Arkose from S½ sec. 6, T14N, R7E, about half way up the north slope of Osborne Mountain.

<u>Megascopic</u>: The rock is light gray in color, well sorted, fine-grained and fairly well indurated.

<u>Microscopic</u>: Quartz grains (30%) are mostly strained; one grain has a metamorphic pavement texture. Plagioclase grains (20%) vary in composition from An 26 to An 34. Some plagioclase grains show bent twinning planes. Staining revealed 2% orthoclase. Biotite flakes (15%) are fairly fresh in appearance, although some have been altered to a bleached tan variety with weak pleochroism. The biotite grains have been mechanically squeezed into cracks within some of the minerals and around resistant grains, and in some places have been slightly granulated. Some of the biotite has been altered to chlorite (5%). Muscovite (5%) has been mechanically squeezed, but much less so than the biotite. Calcite grains (10%) are secondary in origin, and in part are an alteration product of plagioclase. The matrix is 15% of the rock, and has a cherty appearance.

Most of the mineral grains are angular, but some are subangular in shape. They average about 0.2 mm. in size.

PLATE XII

Specimen 17: Arkose, Puget Group. Pavement-textured quartz pebble and strained quartz grain. X 400, crossed nicols.

Tilton River District

Exposures of the Puget Group in the headwaters of the Tilton River extend from the latitude of Mineral to about three miles southeast of Morton, a distance of approximately 12 miles. The maximum width of exposed Puget rocks is nine miles. The sequence is composed of over 9000 feet of sandstone, shale, and intertonguing Keechelus(?) units including volcanic flows and volcanic graywacke. Numerous dikes and sills intrude the layered sequence. The rocks are folded into a small anticlinorium that plunges south and southeast beneath the overlying Keechelus volcanics and appear to be underlaid by the Older Volcanics.

In the northern part of the Tilton River district are exposures of volcanic graywackes and clastic-volcanic rocks of Keechelus aspect that are interbedded with rocks of the Puget Group, but because of the reconnaissance nature of the field work in this district, these various rock types have not been differentiated on the geologic map. In the upper portion of the Puget Group of the northern part of the district, sedimentary rocks are more prominent than volcanic rocks. Toward the bottom of the section in this same area, volcanic rocks are more prominent, and because of their stratigraphic position are believed to be equivalent to the Older Volcanics.

In the southern part of the district, the Puget Group does not contain volcanic rocks of Keechelus aspect. The dividing line between the northern and southern part of the district, along the valleys of West and South Fork, seems to be fairly sharp. It is not known whether this line is due to a rapid facies change or is due to faulting.

Outcrops of the Puget Group occur along the many logging roads of the area, and in the tributaries of the Tilton River. Good exposures of light gray arkose occur along State Highway 5 about two miles north of Morton in SE¼ sec. 25, T13N, R4E and SW¼ sec. 19, T13N, R5E, in sec. 18, T12N, R5E along the new highway cut three miles southeast of Morton, and ½ mile northwest of Morton on the west side of the bridge over the Tilton River in sec. 34, T13N, R4E. Shale exposures can be seen along State Highway 5, north and east of Morton.

A detailed investigation of the Tilton River district was not undertaken, consequently the stratigraphic and structural relationships are imperfectly known. The information gathered, however, is of value since it adds to Culver's work (1919, pp. 108-118).

Contacts

The lower contact of the Puget Group in the Tilton River district is unknown. It is presumed, however, that Puget rocks overlie the Older Volcanics, since numerous exposures of volcanic rocks are found in the Tilton River valley stratigraphically below many hundreds of feet of Puget Group rocks. The volcanics appear to be exposed in the uplifted center of the south-plunging anticlinorium.

The upper contact on both sides of the Tilton River valley is obscured by talus and vegetation, but on the basis of slightly diverging rock attitudes in the two groups, the middle part of the Keechelus Group (Tek A, pl. XXXVI, p. 154) is believed to lie unconformably above the Puget Group. Also, cross sections indicate that the thick section of Puget rocks exposed on the western side of the valley may be cut out on the eastern side of the valley by an unconformity(?)

(fig. 1, p. 41). There are, however, the possibilities of either a rapid eastward thinning of the Puget Group to the east, or of faulting at the eastern contact.

On the western side of the Tilton River valley, the contact of the Puget Group with the overlying Keechelus Group was crossed in two places. To the north, in SE¼ sec. 23, T14N, R4E, the uppermost Puget Group rocks are coarse- to fine-grained, cross bedded, tan colored sandstone with thin interbedded coaly layers and fossil leaves, that is overlaid by a fine-grained porphyritic basalt believed to be part of the Keechelus Group. The rocks deposited above the basalt are obscured by talus from a succession of greenish-gray, and gray volcanic breccias and pebble conglomerates that are definitely part of the Keechelus Group.

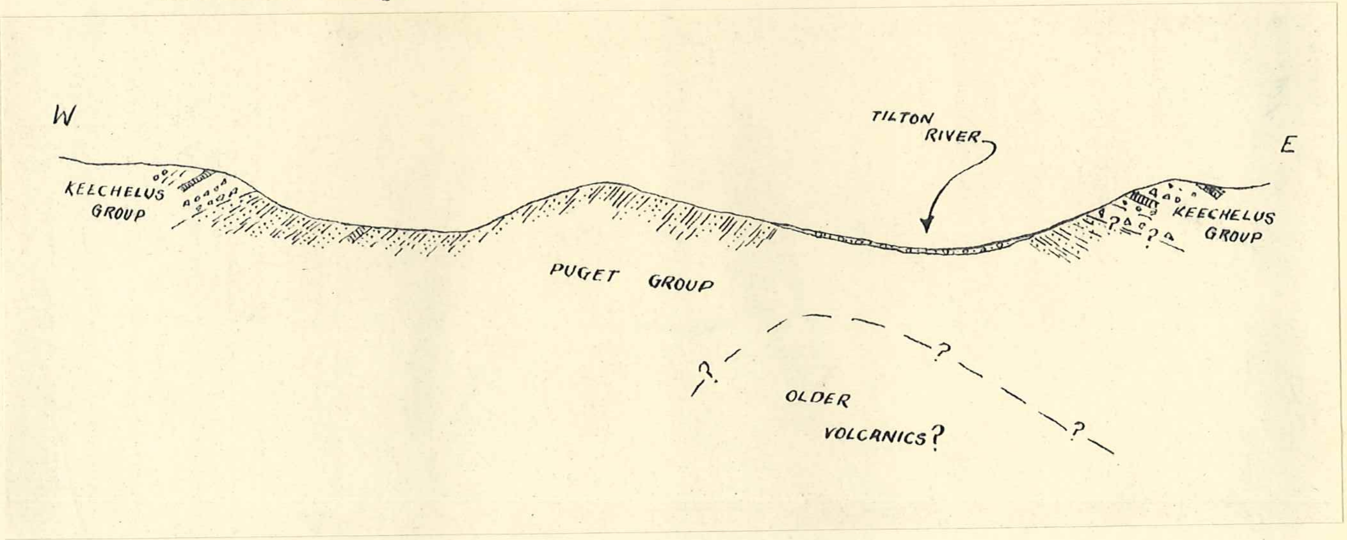


Figure 1. Diagrammatic section across the Tilton River valley showing the possible unconformity between the Keechelus Group and the underlying Puget Group. The Older Volcanics presumably underlie Puget rocks.

The western Puget-Keechelus contact was crossed again about four miles south of the above described outcrop in NW¼ sec. 3, T13N, R4E.

Here, the upper part of the Puget Group is a well bedded, fairly well indurated, well sorted, yellow-brown sandstone overlaid by a dark brown volcanic breccia of Keechelus type that contains red and black angular to subangular-shaped fragments that average about ½ inch in longest dimensions.

On the eastern side of the Tilton River valley, in secs. 21 and 22, T14N, R5E, is a succession of volcanic graywackes and flows with some interbedded gray to buff-colored, well-bedded, fine-grained, muscovite-bearing sandstones and arkoses. The volcanic rocks may be lower tongues of the Keechelus Group. The Puget-Keechelus contact located in NW¼ sec. 22, T14N, R5E is placed at the top of a two foot(?) bed of light gray, medium-grained muscovite-bearing sandstone that clearly overlies a black basalt flow. East of this sandstone outcrop are only volcanic breccias and volcanic flows.

Farther south, in the South Fork and Fern Gap areas, the contact is covered, and its trace is only generally known.

Lithology

Sedimentary Rocks

The sedimentary rocks in the southern part of the Tilton River district are very similar to the rocks of the Nisqually River district. The sandstones are well-bedded to massive, thick- to thinly-bedded, with some beds showing well-developed lamination planes, and are coarse- to fine-grained. They range in color from light gray to brown, have occasional ripple marks, and sometimes contain angular shale chips. The sandstones usually, but not always, contain muscovite and biotite. Conspicuous light gray sandstone and arkose beds sometimes are as much as twenty feet or more thick, and usually show some cross bedding.

In the northern part of the Tilton River district are beds of dark gray-green to green-colored, medium- to coarse-grained graywackes very similar to the rocks in the lower and second Keechelus tongues in the Ashford-Goat Creek section, and to the rocks of member B of the Keechelus Group near the eastern border of the Elbe-Packwood area. These green-colored graywackes appear to be interbedded with arkoses and shales, but the exact relationships are unknown. The graywackes crop out southward from the northernmost Puget outcrops in SW$\frac{1}{4}$ sec. 6, T14N, R5E to West Fork in E$\frac{1}{2}$ sec. 35, T14N, R4E, but are not found farther south. West of Mineral, graywackes grade downward into coarse andesite cobble conglomerate, and are succeeded upward by light gray massive arkose beds near the contact with the Keechelus Group.

Shale is found throughout the area and is commonly interbedded with sandstone. It varies in color from black to gray and brown, is fissile to massive, well-indurated to very friable, and sometimes is conchoidally fractured. Occasional thin lignitic coal layers are found, and in many places carbonaceous material occurs along bedding planes within the shale. Some areas of the Puget Group in the Tilton River district have been mined for coal, but thick coal outcrops are not numerous.

Petrographic Description

The megascopic as well as the microscopic characters of the sedimentary rocks are remarkably similar to those of the Nisqually River district. Individual mineral percentages vary, but in general the mineral composition of the rocks in the two districts are similar (fig. 2, p. 52).

A few specimens from scattered localities are described geographically from north to south. Not attempt is made at correlation.

Specimen 19: Volcanic graywacke from SE$\frac{1}{4}$ sec. 12, T14N, R4E near East Creek. This specimen may be from a tongue of the lower Keechelus Group in the Puget Group.

Megascopic: The specimen is a coarse- to fine-grained, greenish-gray, poorly sorted, well-indurated graywacke.

Microscopic: The matrix (10%) is difficult to distinguish from the rock fragments because of similar compositions and alteration, but is apparently a mixture of finely divided argillaceous material and very fine grained rock and mineral fragments. Antigorite (5%) occurs in the matrix, and as a thin film around many of the grains. In places the antigorite grows in voids between grains as small fibrous crystals.

Andesite fragments (75%) are of several types with differing textures and colors. Colors are red (alteration of magnetite to hematite), black (abundant magnetite? dust in the matrix), gray and white. Most of the fragments have micro-porphyritic textures, and none are vesicular. Among the mineral fragments, plagioclase (5%) is probably andesine and is mainly kaolinized. Only one observed plagioclase grain is zoned, but most show albite twinning planes in varying degrees of clearness. Pyroxene grains (1%) are small fragments of larger crystals, most of which are clear, but some are rimmed with antigorite. The rock and mineral fragments are angular to subangular in shape although some are rounded, and average about 0.8 mm. in size.

Specimen 20: Impure arkose from N$\frac{1}{2}$ sec. 13, T14N, R4E along a logging road near East Creek.

Megascopic: A light-medium gray-green, fine-grained, well-sorted sandstone containing some muscovite flakes.

Microscopic: The matrix (35%) is composed of argillaceous(?) material and very finely divided quartz and feldspar(?) grains. Angular quartz grains comprise 25% of the rock, and some show strain shadows. Orthoclase (10%) is usually slightly cloudy with kaolin. Plagioclase (5%) varies in composition from An 28 to An 40. Chlorite (5%) is altered in part from biotite grains and in part from matrix material. Muscovite and sericite(?) are 1% each. Microcline is approximately 0.1% of the rock. Magnetite (0.1%) occurs as a few isolated grains, some of which have formed due to the release of iron during the alteration of biotite to chlorite, but most of the magnetite grains are transported particles. Rock fragments are composed of chert (10%) and andesite (5%). The andesite fragments have very small feldspar laths set in a matrix altered to a reddish hematitic material. The rock and mineral grains are mostly angular in shape, and they average 0.16 mm. in size.

Specimen 21: Arkose from C., sec. 3, T13N, R4E near the upper contact of the Puget Group on the west side of the Tilton River valley.

Megascopic: A medium gray, medium-grained, well-sorted, muscovite-bearing arkose.

Microscopic: The matrix (5%), composed of finely divided quartz(?) and feldspar(?) grains and brownish argillaceous material, occurs in isolated pockets between rock and mineral fragments. Rock and mineral fragments comprise 95% of the rock. Quartz grains are 30% of the rock. Orthoclase grains (20%) are usually slightly altered to kaolin. Plagioclase grains (5%) vary in composition from An 25 to An 35. Some plagioclase grains have bent twinning lamellae, and are partially altered to kaolin and calcite. Microcline grains are 1% of the rock. Biotite flakes (15%) are in all stages of alteration from a dark brown, strongly pleochroic variety to a light brown, weakly pleochroic biotite(?), and some are partially altered to a greenish-brown chloritic material. In places biotite grains are intergrown with muscovite, and, like in some specimens from the Nisqually River district, the micas are squeezed between more resistant grains (pl. XIII, p. 46). Muscovite is 3% of the rock. Chlorite is 5% of the rock, and most of it is an alteration product of biotite. Magnetite grains (2%) occur as an alteration product of biotite(?), and as transported grains. Chert fragments 4% of the rock. Fine-grained shale ships (2%) contain abundant carbonaceous material between bedding laminae. The mineral grains are angular to subangular in shape and average 0.3 mm. in size.

Specimen 22: Arkose from SW¼ sec. 19, T13N, R5E along State Highway 5 just north of South Fork.

Megascopic: Light gray, medium-grained, well-sorted, muscovite-bearing arkose.

Microscopic: Most of the matrix was lost during the preparation of the thin section, but that which is left is fine-grained quartz and feldspar grains. Argillaceous material is absent. Quartz, the dominant mineral of the rock, is angular in shape and shows strain sha-

PLATE XIII

Specimen 21: Arkose, Puget Group. Note broken and bent muscovite grain in center of photograph. X 400, crossed nicols.

dows. Many of the quartz grains have highly irregular borders due to a secondary addition of silica. Orthoclase, 15% of the rock, has been kaolinized. Plagioclase grains are minor in amount, and vary in composition from An 25 to An 35. Microcline, muscovite, calcite and siderite grains are minor in amount. Chert fragments are rather abundant. One highly carbonaceous sandstone fragment was observed. The rock and mineral particles are angular in shape, and average about 0.3 mm. in size.

Specimen 23: Arkose from SE¼ sec. 25, T13N, R4E along State Highway 5, 1½ miles north of Morton.

Megascopic: Light gray, medium-grained, well-sorted arkose.

Microscopic: The matrix (50%) consists of finely divided quartz(?) and feldspar(?) grains, secondary calcite and cliachite crystals, and a minor amount of argillaceous material. The cliachite is altered from an unknown material within the matrix. Quartz grains are about 30% of the rock, and some have streain shadows. Orthoclase is 10% of the rock. Plagioclase grains (1%) vary in composition from An 26 to An 34. Myrmekite is 0.1% of the rock. Chert fragments are 10% of the rock. The mineral grains are angular to subangular in shape, and average 0.2 mm. in size.

Specimen 24: Shale from NW¼ sec. 36, T13N, R4E along State Highway 5 about one mile north of Morton.

Megascopic: A dark gray, silty, well-indurated, fissile shale.

Microscopic: The matrix (25%) is composed of finely divided quartz and feldspar(?) grains along with brown-colored argillaceous material. Quartz grains (35%) are angular in shape. Orthoclase fragments are 15% of the rock, and many show a cloudy kaolin alteration. Plagioclase grains (2%) are mostly clear, although some are slightly altered to kaolin. Biotite grains (15%) are concentrated along bedding planes within the rock, and are bent around resistant quartz and feldspar grains. Some of the biotite grains are altered to a light tan-colored, weakly pleochroic mineral. Muscovite grains (5%) are bent around resistant grains in a manner similar to the biotite grains. Chlorite (1%) occurs as an alteration product of biotite. Leucoxene grains are about 5% of the rock, magnetite is 0.1%, calcite is 0.1% and kaolin is 1% of the rock. There are 1% carbonaceous fragments concentrated along indistinct bedding planes, and usually are closely associated with the biotite grains. The mineral grains are angular in shape and average about 0.04 mm. in size.

Specimen 25: Pebbly arkose from an outcrop in C., sec. 18, T12N, R5E along State Highway 5 about three miles southeast of Morton.

Megascopic: Pebbly, coarse-grained, fairly well indurated, poorly sorted arkose that contains abundant quartz, chert and feldspar fragments.

Microscopic: Although most of the matrix was lost during the preparation of the thin section, this specimen is included because of its unusual coarseness and because of the high percentage of large chert fragments and quartz grains. Quartz and chert fragments comprise most of the rock. Most of the quartz grains occur within the chert fragments as small veins, some of which display cockscomb structure (pl. XIV, p. 49). Some of the quartz grains have secondary replacement borders. Other observed mineral grains are microcline, muscovite and sericite(?). The maximum grain size in the thin section is 3.0 mm. Most of the mineral grains are subangular in shape, although some are angular and some are well-rounded.

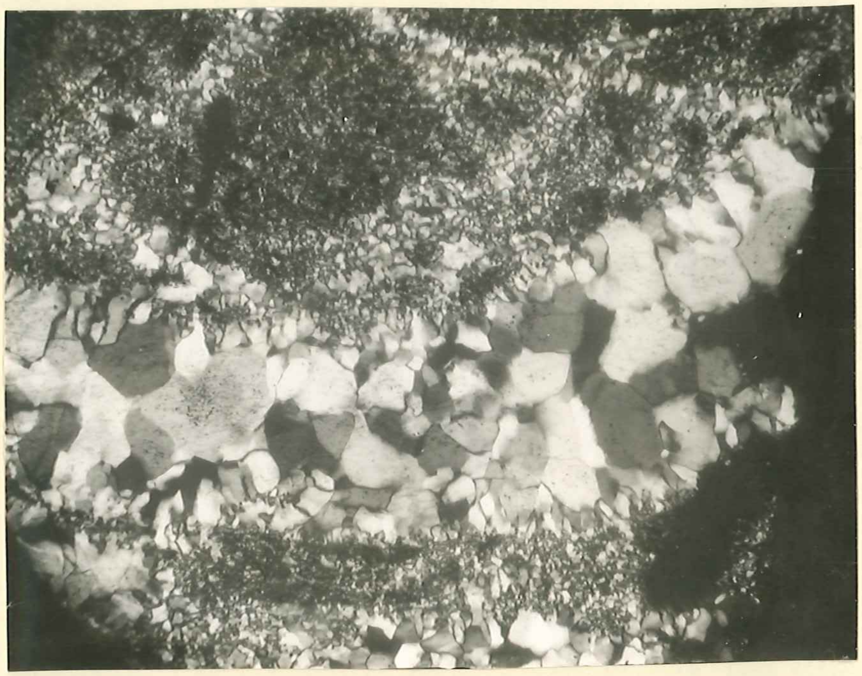
Extrusive Igneous Rocks

Because of the reconnaissance nature of the field work in the Tilton River district, it is difficult to extimate the number of volcani flows, or to give a significant summary of their composition. In the field, many of the flows appear to be basalt, but every sample examined under the microscope is andesite.

In the Tilton River district, the relationship of an outcrop of volcanic rock to surrounding sedimentary rocks is often obscure, although in a few places the volcanics can be positively identified as flows. It is usually difficult to distinguish between flows, dikes and sills.

A few specimens from scattered localities are described petrographically, and since exposures are few, no attempt is made at correlation.

PLATE XIV



Specimen 25: Pebbly arkose, Puget Group. Quartz veinlet in chert pebble with coxcomb structure. X 320, crossed nicols.

Petrographic Description

Specimen 26: Andesite from SW$\frac{1}{4}$ sec. 19, T13N, R5E along State Highway 5, just north of South Fork. The specimen is from a flow that is interbedded with sandstone and shale.

Megascopic: Dark gray to dark green-gray andesite with abundant feldspar phenocrysts.

Microscopic: The rock has a felty texture and contains about 70% plagioclase (An 45); 20% are phenocrysts, and 50% are matrix feldspar crystals. Many of the plagioclase grains are cloudy due to their partial alteration to kaolin. Pyroxene crystals (25%) are generally altered to a yellow-brown chloritic material. Calcite (2%) is altered from the feldspar crystals and matrix material. Chlorite is about 20%, antigorite is 1%, and opaque minerals (magnetite?) are 2% of the rock.

Specimen 27: Andesite from SW$\frac{1}{4}$ sec. 9, T13N, R4E.

Megascopic: The rock is dark medium green in color and contains plagioclase phenocrysts.

Microscopic: The rock is fine-grained, holocrystalline and porphyritic in texture. Phenocrysts of plagioclase reach a maximum size of 0.5 mm. Matrix plagioclase crystals are equant in shape.

Plagioclase grains are 50% of the rock. Phenocrysts of plagioclase (An 45) are 20%, many of which show aligned inclusions of small pyroxene grains that are partially altered to chlorite. Some of the phenocrysts have been altered to kaolin. The matrix plagioclase crystals (An 30) have been considerably altered to kaolin, and in general are twinned and zoned. Relatively fresh, fine-grained pyroxene grains comprise 22% of the rock; 2% are phenocrysts, and 20% occur in the ground mass. Chlorite (30%) is an alteration product of an originally glassy(?) matrix.

Specimen 28: Andesite from C., sec. 14, T13N, R4E, along a logging road about two miles west of the Tilton River.

Megascopic: The rock is gray-green to green in color, and has scattered milky plagioclase phenocrysts.

Microscopic: The rock has a felty texture and is hemicrystalline. Plagioclase crystals are 45% of the rock; 15% are phenocrysts (An 60), and 25% occur as fine-grained matrix grains (An 30). Many of the feldspar crystals have been kaolinized. Kaolin is about 10% of the rock. Augite crystals are 5% of the rock, some of which are included in the feldspar phenocrysts. Chlorite (15%) occurs as an alteration product of the pyroxene crystals. Calcite (5%) is an alteration product of plagioclase grains. Glass is 15% of the rock. Magnetite grains are 1%. Quartz crystals (5%) occur as very small crystals, some of which appear to be secondary in origin.

Specimen 29: Andesite from C., sec. 22, T13N, R4E, about three miles northwest of Morton along Connelly Creek.

Megascopic: The rock is medium gray apple green in color, is aphanitic in texture, and contains a few large, scattered feldspar phenocrysts.

Microscopic: The matrix (95%) is composed of small, felty, mostly kaolinized and partially calcified plagioclase laths. The original glassy matrix has been altered to chlorite(?), and has relatively large irregular-shaped patchy areas of quartz. Euhedral plagioclase phenocrysts (An 50) are 5% of the rock, many of which are kaolinized, and some of which are completely altered to calcite and small clear quartz crystals. Matrix feldspar laths (An 30) comprise 20% of the rock. Chlorite crystals are 35%, secondary quartz crystals are 20%, secondary calcite is 15%, and scattered magnetite grains are 0.1% of the rock.

Relationship between the Tilton River and Nisqually River Districts

A direct correlation of the Puget Group between the Tilton River and Nisqually River districts cannot be made because of a cover of younger volcanic flows and glacial debris, but for the reasons stated below, they appear to be essentially equivalent.

Fossil leaves indicate that the Puget Group of both areas was deposited in the upper Eocene epoch (pp. 54-57), although refined correlation by leaves is virtually impossible.

The Puget rocks in both districts are lithologically very similar. The significance of the mineral percentages listed in figure 2, p. 52, however, is questionable because the samples were selected for thin section study on the basis of degree of induration. The results, however, do indicate a similar composition of source areas of the rocks.

	Nisqually River District	Tilton River District
Quartz	30%	30%
Orthoclase	9%	14%
Plagioclase	20%	3%
Muscovite	4%	3%
Biotite	10%	12%
Chlorite	3%	3%
Calcite	11%	15%

Figure 2. Comparison of mineral percentages of sandstones from the Puget Group from the Nisqually River and Tilton River districts.

The sandstones of both districts are generally fine-grained, well-sorted and contain dominantly angular, but some subangular and a few rounded grains. The matrices of the sandstones vary from "clean" arenaceous to "dirty" argillaceous material. Quartz, muscovite and plagioclase grains are consistently present in all the samples. Orthoclase is occasionally present, and is most abundant in samples from the southern part of the Tilton River district. Microcline, perthite and chert fragments are occasionally present. Biotite occurs in almost all the samples. Some of the biotite grains are altered to a light brown, "bleached" variety which may be calciobiotite, a type containing 14% CaO (Dana, 1950, p. 664). Chlorite is a common alteration product of biotite. Magnetite grains are present in slight amounts in almost all the studied thin sections, but are inconspicuous because of their small percentage. Accessory minerals are very minor, and usually occur as finely divided crystals within the matrix. None of the examined Puget Group rocks contain recognizable volcanic-derived materials.

The regional structural pattern suggests a possible equivalence between the Puget rocks exposed in the Tilton River and Nisqually River districts (pl. XXXVI, p. 154).

Age of the Puget Group

General Statement

The age of the Puget Group was first thought to be Cretaceous (Willis, 1880, p. 759). Willis states that

> Collections made by the Northern Transcontinental Survey have been submitted to Professor J.S. Newberry, who considers them the equivalent of the Laramie east of the Rocky Mountains, and of greater antiquity than the Tertiaries of Bridge Creek and John Day's Valley in eastern oregon;...
>
> A hint of their (Cretaceous) existence is found in some indistinct agatized casts, of oval cross section and about 2" long, which were brought from a conglomerate on the upper Skookumchuck southeast of Tenino; they were unfortunately lost but were apparently casts of baculites.

White considered the Puget Group to be equivalent to the Tejon Group of California (at that time thought to be lower Eocene), but said that the marine Tejon Group (probably the Cowlitz formation of Washington) and the Puget Group could not be correlated by fossils because one fauna is marine and the other is estuarine. He tentatively dated the Puget Group as Eocene because marine Eocene fossils

("Tejon Species") on the Duwamish River are stratigraphically related to nearby typical exposures of Puget rocks, but he does not state what the stratigraphic relationships are (White, 1888, p. 448).

Weaver (1937, p. 55) concludes that the major portion of the Puget Group was deposited in middle and late Eocene time, but that the lowermost deposits may be early Eocene in age, and that the uppermost deposits may be of earliest Oligocene age.

Fossil leaves found in the Puget Group of both the Nisqually River and Tilton River districts indicate an Eocene age, but do not permit a more accurate age determination. It seems likely, however, that the Puget Group rocks of both districts were deposited during the latter part of the Eocene epoch.

Nisqually River District

The following floras were collected in the uppermost member (third Puget tongue) of the Puget Group from the Copper Creek drainage basin, and, although the stratigraphic relationships are indefinite, the leaves apparently are from near the middle of the unit. The inexactness of floral age determinations justifies the treatment of these fossils as an assemblage, even though the third Puget tongue is at least 2000 feet thick. Collections made by the writer and by Roland W. Brown of the U.S. National Museum are listed separately.

University of Washington Locality WA 231: NE$\frac{1}{4}$ sec. 19, T15N, R7E.

Carya magnifica (Knowlton) La Motte (No. 13700)

Cercidiphyllum arcticum (Heer) Brown (No. 13701)

Glyptostrobus dakotensis Brown (No. 13702)

Ulmus sp. (No. 13703)

University of Washington Locality WA 232: NE$\frac{1}{4}$ sec. 18, T15N, R7E

Cercidiphyllum arcticum (Heer) Brown (No. 13704)

Carya magnifica (Knowton) La Motte (No. 13705)

U.S. Geological Survey Copper Creek Locality

Metasequoia occidentalis (Newberry) Chaney

Cercidiphyllum sp.

According to Brown (1953, written communication), the fossils from the Copper Creek area are Eocene, "perhaps late". Since these fossils are from the upper part of the Puget Group, it seems likely that they are of upper Eocene age. That the Puget rocks of this district are not as young as Oligocene, is indicated by upper Eocene leaves (Univ. Wash. Locality WA 235, p. 111) collected from the middle part of the Keechelus Group hundreds of feet stratigraphically above the uppermost Puget-Keechelus contact.

Statements of the environmental conditions of deposition that are based upon such a small collection of leaves are at best generalizations. Brown, however, states that Carya, Ulmus and Metasequoia "could be regarded as streamside or lowland inhabitants" and that Glyptostrobus may indicate " a moist environment", but he hesitates to make definate statements (Brown, 1954, written communication).

Tilton River District

Fossil leaves in the upper portion of the Puget Group west of Mineral indicate an upper Eocene age. Leaves collected by Brown are included in the localities listed below.

U.S. Geological Survey Mineral Locality: SE$\frac{1}{4}$ sec. 12, T14N, R4E.

Woodwardia sp.

Equisetum sp.

Pinus sp.

Cercidiphyllum elongatum Brown

Cinnamomum dilleri Brown

Alnus sp.

Calyptranthes sp.

Laurophyllum sp.

Platanophyllum sp.

Of this assemblage, Brown states "That the flora has species in common with the Comstock flora in Oregon, said to be of late Eocene age, and also with the McIntosh and Renton floras" (1953, written communication). The Renton flora is probably late Eocene, but the McIntosh formation is supposedly middle Eocene, an age determination by W. Rau (Snavely, et al., 1951) based upon microfaunal evidence. The writer, however, believes that the Puget Group in the Tilton River district is equivalent to the partially marine, upper Eocene Skookumchuck formation rather than equivalent to the McIntosh formation (p. 58).

University of Washington Locality WA 233: SE$\frac{1}{4}$ sec. 12, T14N, R4E (same as U.S.G.S. Mineral locality).

Sparaganium antiquum (Newberry) Berry (No. 13706)

Platanophyllum whitneyi (Lesquereux) MacGinitie (No. 13707)

University of Washington Locality WA 234: SE$\frac{1}{4}$ sec. 23, T14N, R4E.

Equisetum sp. (No. 13708)

Laurus sp. (No. 13709)

Brown states that *Equisetum* and *Sparaganum* indicate a moist environment. The general fossil types and rock associations of the Tilton River district indicate a depositional environment similar to the depositional environment of the Puget rocks in the Nisqually River district.

Correlation

Nisqually River District

The Puget Group exposed in this district extends continuously northward to the Puyallup River, but cannot be traced farther north because of an unconformable(?) cover of young volcanic flows (Leanard Gard, 1955, oral communication). However, the north-south structural trend and the lithologic character of the rocks in the Nisqually River district, strongly indicate that they are equivalent to a thick section of Puget rocks exposed along the Mowich Lake road, thirteen miles north of the present area.

The correlation of Puget rocks in the Nisqually River district with Puget rocks exposed near Seattle is not as positive, but on the basis of lithology, fossil leaves, and stratigraphic position, they appear to be equivalent.

A direct correlation between the rocks in the Nisqually River and

Tilton River districts cannot be made, but they are probably essentially contemporaneous (pp. 51-53).

Tilton River District

The rocks of this district are correlated by Snavely, et al. (1951) to the middle Eocene McIntosh formation of the Centralia-Chehalis area on the basis of fossil leaves. The rock patterns shown on the compiled geologic map (pl. XV, p. 60), however, suggests the equivalence of the upper Eocene Skookumchuck formation to the Puget Group. As shown on the compiled map, the Skookumchuck formation in the southeast corner of Snavely's map can be easily correlated to the Puget Group shown on the western side of Culver's plate XIX (1919, p. 103). With this 1½ mile gap bridged, the Skookumchuck formation (Puget Group) can be followed southeast to within five miles of Puget rocks exposed in the Tilton River district. The attitudes of Puget rocks in the Tilton River district and those of the area to the west indicate an intervening syncline, and the Puget rocks are probably continuous beneath the Keechelus rocks which are exposed in the syncline. The Skookumchuck formation is lithologically similar to the Puget Group of the Tilton River district, but in the Centralia-Chehalis area it has interbeds of marine rocks. The marine interbeds contain upper Eocene megafossils, identified by H.E. Vokes, that "correlate with the fauna from the upper Eocene Cowlitz formation of the type locality in Cowlitz County, Washington" (Snavely, et al., 1951). A meager fauna of shallow-water foraminifera, studied by H.G. Billman, is considered to be the same as the fauna found in the upper Eocene

Cowlitz formation exposed along Olequa Creek near the town of Winlock, Washington. Since the Skookumchuck formation of the Centralia-Chehalis area appears to be laterally equivalent to the Puget Group exposed in the Tilton River district, the age of at least part of the Puget Group is considered to be upper Eocene rather than middle Eocene as suggested by Snavely.

If the Skookumchuck formation and the Puget Group are equivalent to each other, then the Older Volcanics which lie stratigraphically beneath the Puget Group must be equivalent to the volcanic rocks of the Northcraft formation which lie beneath the Skookumchuck formation in the Centralia-Chehalis area.

A diagrammatic, east-west stratigraphic section drawn from the Centralia-Chehalis area to the Cascade crest graphically represents the above assumptions (pl. II, p. 7).

MIDDLE AND UPPER KEECHELUS GROUP

General Statement

The Keechelus Group, first named as the Keechelus andesitic series by Smith and Calkins (1906, pp. 8-9), is part of an extensive volcanic field extending from the Snoqualmie Pass region of Washington into Southern Oregon. Similar volcanic rock types extend as restricted patches north of Snoqualmie Pass into northern Washington. The type section for Keechelus rocks is not designated, but is considered to be the greenish dacite breccias exposed along Lake Keechelus east of Snoqualmie Pass. The thickness of the Keechelus volcanics in the type region is estimated to be 4000 feet (Smith and Calkins, 1906).

Keechelus rocks of the Elbe-Packwood area have been divided into the upper, middle and lower Keechelus Group (pl. XXXVI, p. 154). Tongues of Keechelus rocks which are interbedded with the Puget Group in the Nisqually River district (pp. 15-38) are included within the lower Keechelus Group. The middle Keechelus Group includes upper Eocene volcanic rocks which lie above the Puget Group and below volcanic rocks of Oligocene(?) age. The Oligocene(?) volcanic rocks are designated as the upper Keechelus Group.

As described in the literature (Smith and Calkins, 1906, pp. 8-9; Coombs, 1936, pp. 150-165; Abbott, 1953, pp. 42-76), the Keechelus rocks are primarily andesitic pyroclastics with a subordinate amount of volcanic flows. The volcanic flows are composed principally of porphyritic pyroxene andesite, followed in order of decreasing abundance by dacite, basalt and rhyolite. These rocks are generally altered and are characteristically green, but vary widely in color.

In the Elbe-Packwood area, the Keechelus Group is composed mainly of clastic-volcanic rocks and a subordinate amount of pyroclastics and volcanic flows. Most of the rocks are andesitic in composition, although basalt and dacite occur. The rocks are commonly various shades of green and brown, but are also red, pink, gray and black.

The Keechelus Group in the mapped area is at least 10,000 feet thick, and may be as much as 20,000 feet thick (pl. XXXVII, sec. DD', p. 155), although undetected faulting may repeat the section.

The age of the Keechelus Group, generally regarded as Oligocene, is, in the present area, believed to be in part upper Eocene because of its intertonguing relationship with the Puget Group (pp. 17-38). It may extend into the Oligocene(?), and its lower part may be as old as middle(?) Eocene.

Previous Work

Smith and Calkins (1906, p. 8) found that Keechelus rocks consisted stratigraphically of two parts, "lower" and "upper", but were unable to separate them. Warren (1941, pp. 795-802) working in the Mt. Aix quadrangle south of the area worked by Smith and Calkins, differentiated the upper and lower parts of the Keechelus and proposed the name Fifes Peak Andesite for the upper part of the Keechelus. The name Keechelus was restricted to the lower part of the Keechelus series. Abbott (1953, pp. 42-70), also working in the Mt. Aix quadrangle, divided the restricted Keechelus into four parts: the Cougar Creek Andesite, Morse Creek Andesite, Richmond Breccias, and Mount Aix Andesite, but these units cannot be recognized in the present area.

The name of Keechelus is used for the volcanic rocks in the Elbe-Packwood area because Coombs (1936, pp. 150-165) traced Keechelus volcanic rocks from the type area near Snoqualmie Pass into Mount Rainier National Park, and similar rocks can be traced from the park into the Elbe-Packwood area.

On the basis of an Oreodont jaw discovered by Grant (1941, pp. 591-593), the Keechelus is currently regarded as Oligocene in age, although Abbott (1953, p. 46) suggests that the Keechelus may include rocks as old as upper Eocene. Work in the Elbe-Packwood area substantiates Abbott's assumption.

Distribution

The middle and upper Keechelus Group includes about 60% of the surface exposures in the Elbe-Packwood area. Excellent outcrops occur in the eastern part of the area along Skate Creek road, in road cuts along Willame Creek, on the northeast slope of Sawtooth Ridge, and throughout the Catt Creek and North Fork Mineral Creek drainage basins in an extensive network of logging roads. In the western part of the area, Keechelus rocks are easily reached by one of the region's many logging roads. The most easily accessible exposures occur along State Highway 5 from Randle to the vicinity of Packwood, but most of these exposures are south of the mapped area.

Contacts

Nisqually River District

The middle Keechelus Group and the Puget Group in this district appear to be conformable, and their contact can be followed eight miles northward to the Puyallup River. The beds in both Groups strike slightly west of north, and dip about 20° to the east. This contact reappears five miles north of the Puyallup River along Mowich Lake road, but cannot be directly connected with the present area (Leanard Gard, 1955, oral communication).

The immediate Puget-middle Keechelus contact is covered by talus near Mount Beljica in the Copper Creek drainage basin. In this area, the first Keechelus outcrop that occurs stratigraphically above the Puget Group in SE¼ sec. 17, T15N, R7E is a crudely bedded, well indurated, chaotically sorted volcanic breccia believed to be laharic in origin.

East of Goat Creek in NE¼ sec. 33, T15N, R7E almost three miles southeast of the above mentioned outcrop, is a similar volcanic breccia believed to be equivalent to the breccia near Mount Beljica. It contains fragments of dark gray to black, dense basalt(?) and olive-green and gray porphyritic andesite that average about one inch in longest dimension, although they are extremely variable in size. The fragments are angular, subangular and rounded in shape. The rock has no visible bedding planes and is very poorly sorted. The matrix of this breccia is gray to gray-green in color, and contains abundant small (¼ mm.) plagioclase crystals believed to be partly authigenic in origin because some of the crystals invade the borders of the rock fragments.

The Puget-middle Keechelus contact was crossed on Osborne Mountain in SW¼ sec. 7, T14N, R7E. The Keechelus here is a coarse-grained volcanic graywacke that directly overlies a light gray, muscovite-bearing, cross-bedded arkose (specimen 18, p. 35). The graywacke is poorly sorted, well indurated (siliceous?), and olive-green to gray in color, with volcanic fragments as much as 2 mm. in size. The fragments are 95% of the rock and are of four to five rock types, ranging from aphanitic to porphyritic in texture, and light to dark gray and olive-green in color. There are quartz(?) grains, abundant feldspar fragments and some augite(?). The exact bedding plane separating the arkose and volcanic graywacke was not observed. An outcrop found farther up the slope (stratigraphically higher) consists of a volcanic breccia similar to the breccia near Mount Beljica and to the breccia exposed near the park entrance.

Tilton River District

Rocks considered to be middle Keechelus disconformably(?) overlie Puget rocks in this district, although the exact contact could not be found (pp. 40-42).

Subdivision of Units

The lower Keechelus Group, which is interbedded with the Puget Group in the Nisqually River district, is discussed on pages 14-38.

The middle Keechelus Group is divided into two parts based upon lithology. Member A, the lowest part of the middle Keechelus consists of a series of undifferentiated volcanic breccias, conglomerates, graywackes, and flows that are interbedded with shales. There are several short discontinuous clastic-volcanic units that can be traced as much as five miles, but are not continuous enough to be regarded as members.

The upper part of the middle Keechelus Group, designated as member B, conformably overlies member A. It is a relatively homogeneous unit composed of a minimum of 5700 feet of coarse pebbly volcanic conglomerates, volcanic graywackes and fine-grained, dark colored shales containing coaly layers. This member can be differentiated only near the eastern border of the area, and apparently thins westward. Rocks similar to those of member B occur as lenses(?) in member A.

The upper Keechelus Group, perhaps as much as 5000 feet thick, includes tuffaceous rocks which crop out in the central part of the region in the Silver Creek depression, and volcanic flows along the eastern border of the area. In both areas the upper Keechelus rocks appear to be disconformable above the middle Keechelus Group.

Lithology

Middle Keechelus Group

Member A

Member A, about 60% of the surface exposures of the Keechelus Group, includes a great variety of volcanic rocks. It can be compared with, but not correlated to the Richmond Breccias in the Mount Aix quadrangle to the east (Abbott, 1953, pp. 62-70), because flow rocks similar to Abbott's Cougar Creek Andesite, Morse Creek Andesite and Mount Aix Andesite also occur within member A. Rocks in member A are also similar to those described by Coombs in Mount Rainier National Park (1936, pp. 152-161).

Rock types include volcanic breccias of laharic and pyroclastic origin, tuff, lapilli tuff, tuffaceous sandstone, volcanic graywacke and conglomerate, tuffaceous siltstone and shale, and andesite, basalt and dacite flows. In places the rocks are interbedded with Puget-type sediments. The rocks vary widely in color, but are prevailingly green and gray-green. The important rock types are described in more detail.

Volcanic Breccias

Volcanic breccias, estimated to be 55% of the rocks in member A, are generally massive, usually chaotically sorted, and well lithified. Some of the beds are as much as 100 feet thick in a single outcrop without visible bedding, as is best seen along the northern side of Sawtooth ridge where glaciers have carved cirque walls as much as a thousand feet high. Here, bedding planes in the massive breccias cannot be distinguished except at a distance, because the only expression of bedding are changes in color and in fragment sizes. The breccias are interbedded with andesite flows, volcanic graywackes, shale and tuff beds. Some breccias contain disseminated carbonaceous fragments.

The rock fragments of the breccias are aphanitic and porphyritic in texture, although some are vesicular and amygdaloidal. These fragments may show various shades of red, gray, green and occasionally they are black. They are angular to subangular to well rounded in shape, and average about two inches in longest dimension, although some are as much as six feet in diameter. There are commonly four to five distinguishable rock types within a single breccia deposit, although occasionally only one or two rock types occur. In places, carbonized wood fragments occur. In some breccias the fragments blend (grade?) into a usually lighter colored green-gray matrix, but more often they have sharp outlines. In places, the breccias grade laterally and/or vertically into volcanic conglomerates or volcanic graywackes.

The matrix of the volcanic breccias, composed of mineral grains and small rock chips which are similar to the larger fragments, varies in color from light green-gray to medium green and black. The green color is caused mainly by secondary chlorite. Milky-white plagioclase grains consisting mainly of broken fragments of larger crystals are ubiquitous. Augite is present in many of the rocks, and hornblende is a very rare constituent.

The breccias are exposed extensively from Skate Creek to the west side of the Tilton River, and from Mount Rainier National Park to the southern border of the area.

The most abundant type of volcanic breccia in the Keechelus Group of the mapped area is apparently of laharic origin. Pyroclastic breccias appear to be less abundant than laharic breccias. Since the recognition of these two types of volcanic breccias is considered important in the stratigraphic evaluation of volcanic deposits, the criteria used to distinguish between them is discussed below.

Distinguishing Features of Laharic and Pyroclastic Breccias

Sorting

Sorting of particles transported by mudflows is chaotic, a criterion used by several authors to recognize laharic deposits (Anderson, 1933, p. 260; Curtis, 1954, p. 458; Rouse, 1937, p. 1281; Williams, 1949, p. 321). As a result of chaotic sorting, lamination planes are absent, and the rock and mineral fragments are not aligned. Within a single deposit, clay- to boulder-sized fragments occur mixed together heterogeneously. The lack of sorting in mudflow deposits is believed to be due to the mechanics of mudflow transportation, in which all the particles move as a unit at about the same rates of speed. Each particle is part of the fluid, and because of the high viscosity does not rise or sink (Anderson, 1933, p. 260). However, since there is a complete gradation from extremely viscous mudflows to the "normal" fluidity of streams, gradations from unsorted breccias to fairly well sorted volcanic breccias and conglomerates can be expected.

Pyroclastic breccias have a distinct though crude sorting. Airborne fragments, influence by wind velocity, force of initial explosion and size, are sorted according to size as they fall back to the earth. The smaller particles travel farther from the volcano and are last to reach the earth, and, as a result, there is a lateral gradation as well as a vertical gradation in fragment size (Shrock, 1948, pp. 330-334).

Bedding Characteristics

Since movement is along the ground, loose material is picked up from the ground and mixed with the particles of the mudflow. Rocks within the lahar may therefore be mixed with ground material, depending upon the induration of the underlying deposit.

A supposed laharic deposit that illustrates this is exposed at the junction of Skate and Johnson Creeks (pp. 75-79). Here, volcanic breccia unconformably overlies a pebble conglomerate with a distinct though irregular contact. In places, the pebble conglomerate is transitional with the overlying breccia. Also, three laharic deposits exposed near Randle (pp. 79-83) have indistinct bedding planes and show a slight mixing at the contacts of the underlying and overlying deposits. The mixing of material along bedding planes at both places indicates that the overlying material moved along the ground rather than through the air.

Bedding planes between pyroclastic breccias and their underlying deposits are usually distinct, regardless of the amount of induration of the underlying material at the time of deposition. Rouse (1937, pp. 1280-1281) states that the "explosion breccias" in the Absaroka volcanics are well bedded, and Anderson (1933, p. 246) states that "...volcanian explosions are usually separated by frequent intervals, so that the deposits are more or less stratified and sorted."

Bomb sags (Shrock, 1948, pp. 334-335) give further evidence that fragments have fallen from the air rather than have traveled along the ground, and are used as one way to distinguish pyroclastic debris from a minor lahar in Oahu, Hawaii (Stearns, 1935, pp. 19-20).

Composition of Large Fragments

Fragments composing laharic deposits may be of one or several types. Lahars of the Mehrten formation in the Sierra Nevada are of two types; monolithologic breccias containing one rock type and heterolithologic breccias with four or five distinguishable kinds of andesite fragments (Curtis, 1954, p. 458).

A lahar will pick up and transport all available loose debris from its source throughout its course. Because of this, heterolithologic lahars are probably more abundant than monolithologic lahars.

Identified laharic deposits in the Elbe-Packwood area are heterolithologic lahars, although monolithologic breccias found in the region may be laharic in origin.

Pyroclastic breccias are more likely to be monolithologic because single explosions usually extrude rocks of one composition, although some foreign material may be torn from the vent or crater walls and be included in the deposit.

Rounding and Texture of Large Fragments

Fragments of lahars are usually angular in shape, although they may show perceptible rounding at considerable distances from their source (Curtis, 1954, p. 458). Because mudflows are very viscous and move as a unit, abrasion of the fragments is reduced to a minimum (Anderson, 1933, p. 260), and originally angular fragments do not become rounded as quickly as in streams. Since the amount of water will vary from lahar to lahar, the amount of rounding of the rock fragments may be different in each.

Liquid pyroclastic particles become rounded during flight. Williams (1949, pp. 20-25) uses lack of rounding of the fragments as a criteria to distinguish mudflow deposits from glowing avalanche deposits (nuees ardentes), but this criterion can be also used to distinguish mudflow deposits from pyroclastic deposits.

Liquid particles aerially ejected from a volcano become vesiculated during flight, and consequently have delicate projections around their peripheries. The projections normally are preserved after deposition unless the rock fragments are reworked by running water or by mudflow transportation. Although abrasion is at a minimum in mudflows, the more delicate projections could easily be destroyed. In thin section, pyroclastic fragments are commonly amygdaloidal, and matrix material may invade former vesicles (pl. XX, p. 85), a microscopic criterion used to distinguish the pyroclastic breccias from laharic breccias in the mapped area. It is recognized, however, that vesicular fragments may also occur in laharic deposits.

Agglutination

Pyroclastic debris may be agglutinated. Liquid particles exploded from a volcano may be in a semi-liquid state when they are deposited, and therefore may adhere and crystallize together. Since rock fragments of mudflows are transported as solids, there can be no agglutination in laharic deposits.

In the Elbe-Packwood area, none of the observed volcanic breccia deposits are agglutinated, although some have an agglutinated appearance which is apparently caused by post depositional deformation.

Rock Associations

Laharic deposits are often associated vertically and laterally with volcanic conglomerates, volcanic graywackes and shales which are definitely stream transported deposits. Williams (1949, pp. 20-25) was able to recognize lahars because they contain water worn boulders and grade laterally into volcanic conglomerates. Lahars of the Mehrten formation in the Sierra Nevada are occasionally interbedded with leaf-imprinted laminated clays, angular-shaped pebble conglomerates and coarse-grained sandstones (Curtis, 1954, pp. 457-458).

In the Elbe-Packwood area many of the volcanic breccia beds are interbedded with shales, volcanic graywacke beds, pebble conglomerates and cobble conglomerates. In places there are gradual vertical gradations from pebble conglomerates to coarse-grained volcanic breccias containing angular fragments.

These associations, although highly indicative of mudflow origin are not conclusive evidence, since pyroclastic rocks may also be deposited upon water laid debris. Gradational contacts, however, would not be expected between a pyroclastic deposit and the deposit upon which it lies.

Initial Dip

Fenner (1937, p. 237), in a discussion of the Early Basic Breccias of the Absaroka Mountains, remarks that hundreds of square miles of nearly horizontal breccia deposits are difficult to reconcile with the fact that breccias should have high initial dips on the sides of volcanoes, such as on Mount Etna and Vesuvius, and states, "...the masses set in motion have an ability to move in their lower courses for long distances over gentle slopes in a manner difficult to conceive but that is attested by abundant evidence."

Mudflows are the answer to Fenner's dilemma, for (1) given enough volume to initiate the flow, they are able to move over extremely gentle slopes (Anderson, 1933, p. 259), (2) they are able to flow over extremely long distances, the longest cited by Anderson (1933, p. 259) is 150 miles through a stream valley, and (3) because of their high viscosity, mudflows are able to carry boulders weighing many tons (Anderson, 1933, p. 260; Cotton, 1944, pp. 243-247).

In the Elbe-Packwood area, dips range from horizontal to 85°, and average 25° to 35°. The structural pattern is in no way suggestive of a cone shape, and dips are directly related to the major tectonic structures (pl. XXXVI, p. 154). This relationship indicates that initial dips were low. The conformity of Keechelus breccias over the estuarine Puget Group in the Nisqually River district, and the flat surface beneath the Keechelus contact in the Mount Aix quadrangle (Abbott, 1953, pp. 46-47) strongly indicates that at least part of the breccias were spread out for many square miles over a region of low relief.

Because of the geologic rapidity of erosion, volcanoes are short lived, and since coarse-grained pyroclastic debris is usually deposited on or close to the parent volcano, it is probable that coarse, unreworked pyroclastics are extremely scarce in the geologic column.

Matrix Characteristics

In the Elbe-Packwood region, most of the volcanic breccias contain angular and rounded, broken mineral grains and altered argillaceous material. Not one of the examined breccias contains glass shards, which are to be expected in pyroclastic deposits. Commonly, both fresh and altered plagioclase grains of similar compositions occur within the same rock, thus indicating different source rocks and different lengths of time for alteration before deposition. Similarly, augite grains are both altered and fresh within a single rock specimen. Argillaceous material is expected in mudflow deposits.

In pyroclastic breccias, at least some glass shards should be in evidence, but none of the examined breccias showed even devitrified glass shards. This negative evidence is not conclusive, but indicates that the breccias may be laharic rather than pyroclastic. Since one layer of pyroclastic debris is expected to be deposited from one explosion, it is likely that mineral grains of the same composition would be in the same stage of alteration, and should not show any rounding.

Carbonaceous Fragments

Disseminated carbonaceous fragments are found in many breccias of the Elbe-Packwood region. Although fragments in a mudflow move as a unit, some mixing by turbulence is expected. As the mudflow moves forward it would pick up fragments along the way, including carbonaceous material from forested region which may occur around a large volcano undergoing active erosion. Stearns (1935, p. 20) uses this criterion to distinguish a mudflow from pyroclastic rocks.

Coarse pyroclastics could, of course, also contain disseminated carbonaceous material if forests were growing within the crater at the time of explosion, but forests would not be expected within the cone of an active volcano. If an explosion did destroy a forest within a cone, the wood fragments would be sorted as to size, and would be more likely to form as layers rather than be disseminated throughout the deposit. If pyroclastic debris fell on a forested region around a volcano, carbonaceous layers would result rather than the dissemination of wood particles throughout the deposit.

Laharic Breccias

Exposures of volcanic breccias are generally too small to determine their origins. Two places, however, are excellent for study; one is near Randle along State Highway 5, the other is along Skate Creek Road. These are discussed below in more detail. Volcanic breccias found throughout the area are very similar to these deposits.

Skate Creek Laharic Deposit

At the junction of Skate and Johnson Creeks in SW$\frac{1}{4}$, projected sec. 22, T14N, R8E is a well exposed outcrop of massive green volcanic breccia lying unconformably above a thin (0-2 feet) dark gray pebbly sandstone layer. The sandstone is underlaid by slate gray to olive-green, silty to clayey shale and mudstone.

The volcanic breccia is massive, poorly sorted and without visible bedding, although the subparallel alignment of authigenic feldspar crystals may be nearly parallel to the depositional surface. Fragments of the breccia are porphyritic or aphanitic in texture, are black, red and olive-green in color, and are angular, subangular, and well rounded in shape. They average about $\frac{1}{2}$", but are as large as eight inches in size. Some scattered, reddish, vesicular bomb shaped fragments are present, and show signs of reworking. Mineral grains consisting of angular to rounded feldspar fragments, and ferro-magnesian mineral grains (pyroxene?), average about 10% of the rock. The breccia con-

PLATE XVI

PROPERTY	LAHARIC BRECCIAS	PYROCLASTIC BRECCIAS
SORTING	Chaotic sorting; may grade vertically and laterally into water laid deposits.	Crude vertical and lateral sorting; coarsest fragments on bottom.
BEDDING	May be crudely bedded.	Often bedded; bomb sags may occur along contacts.
COMPOSITION OF FRAGMENTS	Commonly of several types; may be of one or two rock types.	Commonly of one or two rock types; may contain several types.
ROUNDING AND TEXTURE OF FRAGMENTS	Angular to well rounded; commonly aphanitic or porphyritic, less often vesicular or amygdaloidal; in thin section, borders commonly sharp.	Angular or rounded during aerial flight; fragments may be vesicular or amygdaloidal; in thin section, borders are commonly very irregular.
AGGLUTINATION	Never agglutinated.	May or may not be agglutinated.
ROCK ASSOCIATION	Commonly interbedded with, and grade into water laid deposits.	May be interbedded with water laid deposits.
INITIAL DIP	Usually very low.	Usually very high.
MATRIX MATERIAL	Commonly clastic matrix with argillaceous material. Minerals may show various stages of alteration in the same rock. No glass shards are evident.	Commonly tuffaceous matrix; minerals commonly in same stage of alteration. Glass shards may be evident.
CARBONACEOUS FRAGMENTS	May be disseminated throughout a single deposit.	Mostly absent. May occur disseminated or as layers within a single deposit.

CHARACTERISTICS OF LAHARIC AND PYROCLASTIC BRECCIAS tains scattered carbonaceous fragments and one well preserved pine cone (Picea sp.).

The following is a petrographic description of part of the breccia.

Specimen 34: Volcanic breccia of laharic origin from SW$\frac{1}{4}$ projected sec. 22, T14N, R8E near the junction of Johnson Creek and Skate Creek.

Megascopic: The rock is a gray-green to green, poorly sorted volcanic breccia with light to dark green angular to rounded and irregularly shaped andesite fragments. The rock has white authigenic plagioclase grains with irregular borders, some of which grade into the surrounding matrix material. The rock is clastic in appearance, but shows no alignment of any of the fragments. In the outcrop, the authigenic feldspar crystals have a crude parallel alignment.

Microscopic: The rock contains about 15% fragments, 50% mineral fragments and 35% matrix material. Fragments are predominantly angular, but some are rounded, and range in size from submicroscopic to 2 mm. Authigenic plagioclase grains are as much as 4 mm. in size.

The matrix is composed of very fine-grained material that is partially altered to chlorite, some shadowy feldspar(?) grains that can be observed only in polarized light, and weakly birefringent, unidentified minerals.

Quartz crystals (5%) are secondary in origin. Some of the quartz grains enclose matrix material. Plagioclase grains (20%) occur as authigenic growths (pl. XVII, p. 78), and as remnants of primary grains which are altered to calcite and quartz crystals. Some of the plagioclase grains show faint traces of destroyed twinning planes. Some of the primary plagioclase grains show internal alterations to a clear plagioclase of different orientation. Calcite grains (20%) are often irregularly shaped crystals surrounding a core of plagioclase. Chlorite (3%) occurs as part of the matrix and as part of some of the rock fragments. Kaolin (2%) is an alteration product of some of the plagioclase grains. Magnetite (0.1%) occurs as scattered granules within the matrix.

Rock fragments are of two different types. One type is aphanitic with a felty to pilotaxitic texture. The other rock type may be of sedimentary origin.

The underlying pebble sandstone unit contains well rounded and occasionally spherical pebbles. The pebbles are brown and gray to

PLATE XVII

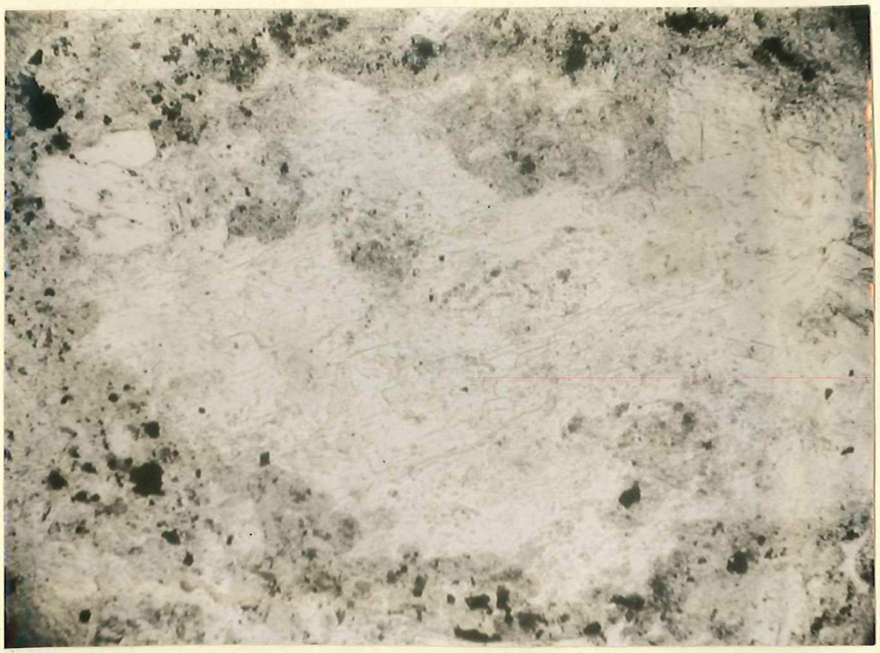


Figure 1. Specimen 34: Laharic Breccia, Keechelus Group. Authigenic plagioclase with highly irregular borders. X320, plain light.

Figure 2. Specimen 34: Same view as above. X320, crossed nicols.

gray-green in color, and occasionally are dense in texture.

The following is a petrographic description of one of the typical pebbles from the pebbly sandstone.

> Specimen 35: Andesite pebble from a pebble sandstone that directly underlies a massive laharic breccia.
>
> Megascopic: The rock is dark gray in color, contains inconspicuous small dark gray euhedral feldspar phenocrysts, and a few small augite(?) phenocrysts.
>
> Microscopic: The rock is holocrystalline and fine-grained. Feldspar crystals (60%) are almost completely altered to calcite and kaolin. Twinning planes are largely destroyed. The altered plagioclase phenocrysts are often lined with secondary albite(?) laths. Magnetite is 5% of the rock. Calcite crystals (5%), often with euhedral crystal outlines, is an alteration product of plagioclase.

In places there is a gradational mixing of the pebbly sandstone with the overlying breccia. The mixing indicates that the breccia was transported along the ground rather than through the air.

Evidence indicating a laharic rather than a pyroclastic origin for the breccia is (1) chaotic sorting, (2) lack of visible bedding, and mixing of the breccia and the underlying conglomerate layer, (3) rounding of some of the fragments and signs of reworking of bomb shaped fragments and (4) disseminated wood fragments.

Randle Laharic Deposit

Near Randle, roadcuts along State Highway 5 expose a magnificent section of Keechelus rocks. The rocks are dominantly volcanic breccias, conglomerates and graywackes, but andesite flows, sandstone and siltstone occur. All the rocks dip southward and strike northeast.

One mile west of Randle, in S½ sec. 7, T12N, R7E, are three well exposed massive volcanic breccia-conglomerate beds. The sorting of the beds is chaotic, with no vertical or horizontal grading of fragment sizes, no alignment of fragments, and no laminations (pl. XVIII, p. 81).

The fragments, composed of porphyritic to aphanitic, very well rounded to angular andesite fragments, range from silt-sized particles to boulders as much as 4 feet in diameter. They are typically green, but are also gray and black in color. Disseminated carbonized wood chips occur. The matrix, composed of silt- to sand-sized particles, is irregularly distributed around the larger fragments.

These deposits are believed to be laharic in origin because (1) the sorting is chaotic, and lamination is absent, (2) the bedding is crude, (3) fragments are generally rounded, which is indicative of much abrasion, (4) the matrix is clastic textured with no trace of glass shards, and (5) the beds contain chips of carbonized wood fragments, presumably picked up and broken by transport along the ground.

The following is a petrographic description of a rock from the middle bed shown in figure 2, page 81.

> Specimen 36: Volcanic breccia of laharic origin from S½ sec. 7, T12N, R7E, one mile west of Randle.
>
> Megascopic: The specimen is a dark gray to black, poorly sorted rock that contains abundant well rounded rock fragments, some angular feldspar grains and some possible ferro-magnesian crystals. Rock fragments are dominantly dark gray in color, although some are greenish-gray, black and red. Conspicuous white calcite grains appear in places within the rock.
>
> Microscopic: Rock fragments comprise about 75% of the rock, calcite cement about 15%, and mineral fragments about 10%.
>
> Rock fragments consist of several types of angular to well rounded andesite fragments in various stages of alteration (pl. XIX, p. 82). The largest fragment in the thin section (3 mm.) is part of a basalt pebble that is very well rounded in shape. The basalt pebble has a dirty brown matrix, authigenic plagioclase(?) grains, augite grains (5%) altered in part to chlorit-

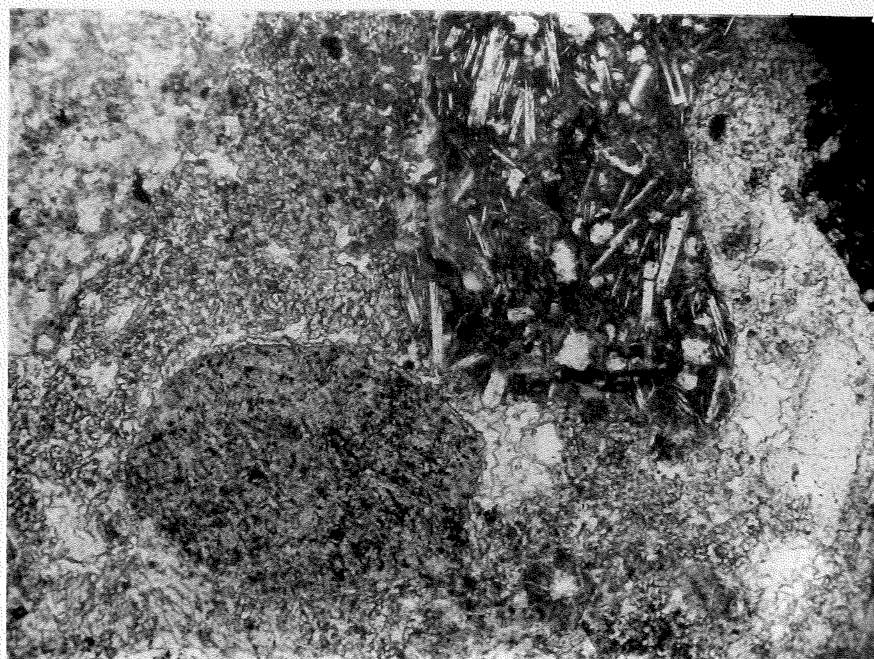
PLATE XVIII

Figure 1. Three crudely bedded lahars near Randle. Layers dip toward camera. View is north.

Figure 2. Closer view of part of figure 1.

Figure 3. Close up of lower bed in figure 2. Note poor sorting, absence of laminae and particle rounding.

PLATE XIX



Specimen 36: Laharic breccia, Keechelus Group. Photograph shows well rounded andesite fragments. Note the abundance of small plagioclase grains in the matrix.
X 240, plain light.

ic material, and some secondary quartz grains. Primary plagioclase grains (An 55) in the basalt pebble are unaltered, are well twinned and show some zoning. Other rock types are (1) andesite(?) fragments with an aphanitic matrix containing extremely altered plagioclase grains, (2) micropilotaxitic andesite(?) fragments with small feldspar laths, (3) a very fine-grained holocrystalline andesite(?), and (4) a few fragments with amygdaloidal texture.

Mineral grains within the breccia are (1) very small augite grains (1%) some of which are fresh, (2) plagioclase grains (6%) with compositions of An 35 to An 45, that are angular to rounded in shape, and partially altered to kaolin, (3) secondary chlorite (3%) that is scattered throughout mineral and rock fragments, and (4) magnetite which occurs as a few scattered grains.

Calcite cement surrounds all grains and in many places includes sparsely scattered submicroscopic matrix material.

Pyroclastic Breccias

Pyroclastic breccias are difficult to recognize because of post-depositional deformation, compaction and mineral alteration; consequently their abundance in the Elbe-Packwood area may be underestimated. Pyroclastic breccias identified under the microscope are megascopically similar to other breccias found throughout the area. Pyroclastic breccias, however, apparently are limited in extent within the mapped area.

Three pyroclastic breccias from widely scattered localities are described. None of these rocks can be distinguished megascopically from other breccias.

Specimen 37: Pyroclastic breccia from SW$\frac{1}{4}$ sec. 5, T13N, R6E along a railroad cut in Mineral Creek valley.

Megascopic: The rock has a dark brown and black matrix containing red-brown, dark brown-green, dark brown and black subangular to angular fragments which blend (grade?) into the matrix. Some of the fragments are porphyritic, none are megascopically vesicular, and one "area" (probably a fragment) contains small quartz amygdules.

Microscopic: Under the microscope, the specimen shows little alteration. Fragments constitute about 65% of the rock, although many are difficult to distinguish from the matrix material. Many of the fragments show highly crenulated borders, the best example of which shows the crenulations filled with matrix material (pl. XX, p. 85). The matrix (35%) in which the rock fragments are set, is composed of angular plagioclase fragments (15%) that are mostly fresh, although some are altered to kaolin. Most of the plagioclase grains are andesine(?) although twinning is generally absent. Pyroxene (augite?) grains, 5% of the rock, are broken fragments of larger crystals. The rest of the matrix is composed of very small rock fragments (andesite?), unidentified submicroscopic material, and a very small percentage of secondary chlorite.

This rock is believed to be pyroclastic in origin because of the crenulated boders and the amygdaloidal structure displayed by many of the fragments.

Specimen 38: Pyroclastic breccia from NE$\frac{1}{4}$ sec. 33, T15N, R7E near the west entrance to Mount Rainier National Park along State Highway 5.

Megascopic: The rock has a light gray-green matrix, and angular rock fragments ranging in color from light gray-green (slightly darker than matrix) to dark green, and black. The green and gray rock fragments are mainly porphyritic. The black rock fragments are generally aphanitic or micro-porphyritic. Milky feldspar crystals are sometimes conspicuous within the matrix.

Microscopic: The rock fragments are 55% of the rock. They are distinctly outlined in plain light, but under crossed nicols they are difficult to distinguish from the matrix. The size of the fragments ranges from submicroscopic to 5 mm. in longest dimension. They are dominantly porphyritic andesites containing untwinned and unzoned, greatly calcitized and kaolinized plagioclase crystals, and ferro-magnesian minerals altered to chloritic material. Many of the andesite fragments have cren-

PLATE XX

Specimen 37: Pyroclastic breccia, Keechelus Group. Re-entrant of light colored clastic-textured matrix in dark colored porphyritic andesite fragment.
X 60, plain light.

ulated borders. The matrix material (45%) contains abundant minute unidentified microlites and recrystallized glass(?) that has been greatly kaolinized. Plagioclase (andesine?) is about 5%, magnetite is about 0.05%, and chlorite is about 1% of the matrix.

On the basis of the highly crenulated borders of some of the andesite fragments, and the devitrified glassy(?) material, the rock is interpreted as a pyroclastic breccia.

Specimen 39: A pyroclastic breccia from E½ sec. 9, T14N, R7E along Teeley Creek about one mile north of Bertha May Lakes.

Megascopic: The rock is a dark green, well indurated breccia containing dark green (mainly), black, gray and red to orange, angular rock fragments.

Microscopic: The matrix of the rock is dark brown with particles grading in size from submicroscopic to the largest particle size. All of the fragments have crenulated borders and amygdaloidal textures. Andesite fragments, 70% of the rock, are porphyritic, aphanitic and amygdaloidal in texture. The plagioclase crystals of the rock fragments range from An 29 to An 49 in composition.

Mineral fragments are plagioclase grains (10%), some of which show strain shadows, epidote (2%) that occurs as an alteration product of some of the plagioclase grains, and secondary chlorite (3%). Chlorite occurs in the minerals and in the rock fragments, but not in the matrix.

This rock is believed to be pyroclastic in origin because of the crenulated borders of some of the rock fragments.

Summary of the Minerals in the Volcanic Breccias

The breccias that were examined contain plagioclase as angular fragments of larger crystals, although many euhedral grains are present. The plagioclase is primarily andesine, and ranges in abundance from 20% to 60%. Some of the feldspar grains are entirely fresh, while others are in various stages of alteration to kaolin, calcite and less often epidote. Augite is often present, but no hypersthene was observed. Hornblende is present in very small amounts, and occasionally there are insignificant amounts of primary quartz grains. Calcite, antigorite and chlorite occur as dominant secondary minerals. Chlorite is almost always present and presumably gives the rocks their characteristic green color.

Volcanic Graywacke

Volcanic graywackes, about 20% of the surface exposures of member A, closely resemble the volcanic breccias except for grain size. They are typically green when fresh, but weather to light brown of various shades. They are usually, although not always, very well indurated, and in places are siliceous(?). Often they are associated with olive-green siltstones and/or pebble conglomerates, but sometimes they are interbedded with greenish tuff, lapilli-tuff and tuff-breccia.

The following is a petrographic description of an unusual siliceous(?) volcanic graywacke.

Specimen 40: Siliceous(?) graywacke from NE$\frac{1}{4}$ sec. 3, T14N, R7E near the Nisqually River along Skate Creek road.

Megascopic: The rock is light gray-green, very tough and in places has the appearance of chert. Bedding planes are marked by dark discontinuous streaks alternating with two inch bands of fine-grained, very hard, light colored material. The rock has the appearance of a flow banded andesite, but in places clastic grains can be distinguished.
Microscopic: Under the microscope, the rock shows graded bedding. Layers grade from coarse sand-sized material upward to silt- and clay-sized material. These layers are approximately an inch in width. Silicic cement is not evident under the microscope. Plagioclase grains (25%) are presumably sodic in composition, but they are not twinned, and the composition was not determined. Augite grains (5%) are prominent, and occur as euhedral grains. The augite is more abundant in the fine-grained silt- and clay-sized material than in the coarse-grained material. Sphene (2%) and calcite

(2%) both occur. Opaque minerals (magnetite?) are 2% of the rock and occur along irregular lamination planes. Two grains of quartz were distinguished, but more may occur in the fine-grained matrix. Most of the rock (about 65%) is composed of silt- to clay-sized material that is too small to be identified by ordinary microscopic methods, but is presumed to be of the same composition as the coarser material.

Volcanic graywackes from the western part of the Willame Creek area are described below.

<u>Specimen 51</u>: Volcanic graywacke from the western end of Willame Creek about one mile northwest of Long Lake in W½ projected sec. 4, T13N, R8E.

<u>Megascopic</u>: The rock is a dark green, well indurated, well sorted, coarse- to medium-grained volcanic graywacke. The mineral grains are mainly angular in shape, but some are rounded.

<u>Microscopic</u>: Angular and rounded volcanic rock fragments are 75%, and feldspar grains are 15% of the rock. The matrix (10%) is very fine-grained argillaceous material, much of which is altered to chlorite.

In general, there are three varieties of andesite rock fragments, the majority of which have felty textures. Some of the fragments show parts of plagioclase phenocrysts. These rock fragments usually have a devitrified glass matrix, a few of them are vesicular, and some are altered to hematite. Some of the fragments are well rounded (pl. XXI, p. 89), but most of them are angular in shape.

Plagioclase grains are mainly untwinned and unzoned, and most of them are angular and fairly fresh, although some are altered to kaolin. The compositions of the plagioclase fragments are An 26, An 28 and An 30. A few leucoxene grains and two augite(?) grains were observed. Magnetite is about 0.1% of the rock. Chlorite occurs throughout the matrix and in many of the volcanic fragments. Some chlorite occurs within feldspar grains as an alteration product of ferro-magnesian inclusions.

<u>Specimen 52</u>: Volcanic graywacke from near the western end of Willame Creek about ½ mile north-east of Long Lake along a logging road in NE¼ projected sec. 9, T13N, R8E.

PLATE XXI

Specimen 51: Volcanic graywacke, Keechelus Group. Photograph shows rounding of andesite fragments.
X 320, plain light.

Megascopic: The rock is a dark green, well sorted, fine-grained, well indurated, volcanic graywacke with irregular black and dark reddish-brown volcanic fragments.

Microscopic: The matrix is about 50%, and the rock and mineral fragments are about 50% of the rock. The matrix (argillaceous?) is brown in color and grades in size from submicroscopic to the largest rock fragment (4 mm.).

Rock fragments are about 40% of the rock and consist of about four different types of andesite. They are mainly felty in texture and contain small plagioclase phenocrysts. Some of the andesite fragments are vesicular.

Mineral grains are plagioclase fragments (6%) which are untwinned and broken, calcite (3%) which is an alteration product of some of the feldspar grains, and about 1% chlorite which replaces ferromagnesian minerals.

Volcanic Conglomerate

Volcanic conglomerates, about 5% of the surface exposures of member A are typically poorly consolidated, fairly well bedded, water-laid volcanic materials with abundant well rounded, sand- to boulder-sized fragments. They are frequently yellow-brown to dark brown in color. The rock particles, usually coated with black to blue-black manganese oxide, are composed of andesite or basalt set in a matrix of tuffaceous(?) and/or silty sandstone. Megascopically the large fragments appear to be basalt, but microscopically they are identified as andesite. Carbonized wood fragments are often found within these deposits. The conglomerates are usually associated with dirty brown to dark gray, poorly to well indurated siltstones and sandstones.

West of the Tilton River, in secs. 27 and 33, T14N, R4E, is a 500 foot series of brown colored, poorly indurated volcanic conglomerates, pebbly sandstones, poorly sorted sandstones and siltstones.

These rocks are fairly well bedded and definitely water-laid, and can be traced 2½ miles along the strike. East of the Tilton River in secs. 3, 4, 5, 9, 16 and 21, T15N, R5E is a 500 foot thick "lens" of light to dark brown friable siltstones, sandstones, pebbly sandstones and conglomerates with some thin interbeds of lignitic coal. This series of rocks extends northward about 4½ miles from Fern Gap.

The two "lenses" described above may belong to the same depositional episode, but the correlation is not certain.

There are many outcrops of volcanic conglomerate in the mapped area, but correlation between them is very difficult because of a heavy forest cover. The conglomerates apparently recur vertically throughout the Keechelus sequence.

Flow Rocks

Volcanic flows occur widely throughout the mapped area, and are about 15% of member A. The upper and lower contacts of single flows are rarely observed in the same outcrop, and usually neither contact can be seen. The thicknesses of individual flows are therefore usually unknown, but observed flows range in thickness from a few feet to several tens of feet. Some occur as individual flows interbedded with volcanic breccias, while others appear to be included within several flows which may total hundreds of feet in thickness.

The majority of the extrusives are structureless, although some show crude columnar jointing, platy structures or crude flow banding. Flows that have well developed columnar jointing and platy structures are generally unaltered, dark gray to black basalts, possibly of later age than the typically altered flow rocks of the Keechelus Group.

Vegetation usually obscures the stratigraphic relationships.

The flows vary widely in megascopic appearance. In the field they are identified as andesite, basalt, dacite and rhyolite in decreasing order of abundance. The rhyolites and basalts are generally aphanitic while the andesites and dacites are porphyritic, usually with abundant plagioclase crystals, often with megascopic pyroxene, and less often with amphibole crystals. Colors vary in the extreme, e.g., white, black, grays, browns, greens and reds. In the Elbe-Packwood area, flows are difficult to distinguish from dikes, but was attempted in the field on the basis of grain size, although occasionally intrusive contacts or bedding plane contacts were seen.

The most abundant flow rocks are porphyritic andesites. Phenocrysts are commonly plagioclase and less commonly augite crystals. Hornblende is occasionally a conspicuous phenocryst, but is usually absent. The most characteristic flows are green, porphyritic andesites with fresh to altered feldspar and augite crystals, and abundant secondary chlorite. Unaltered flows lack the characteristic green color of the typical Keechelus flows.

The following are petrographic descriptions of volcanic flows from scattered localities.

<u>Specimen 42</u>: Quartz bearing andesite from NW$\frac{1}{4}$ projected sec. 3, T13N, R8E on the south slope of Skate Mountain.

<u>Megascopic</u>: The rock is a dark green andesite and contains abundant euhedral to anhedral plagioclase phenocrysts and patchy light and dark green areas.

<u>Microscopic</u>: The matrix contains secondary calcite, chlorite and widely dispersed magnetite dust. Small felty plagioclase crystals which occur in the matrix are 35% of the rock. Plagioclase phenocrysts (5%) are An 32 in composition and are in

all stages of alteration to kaolin and calcite. Chlorite (38%) is apparently an alteration product of biotite and pyroxene(?) grains. Euhedral crystals of calcite (20%) are probably altered from feldspar, but also occur in the matrix as small anhedral patches. Quartz grains (2%) are euhedral to anhedral in shape and apparently are primary in origin. Rutile(?) and magnetite grains are 0.1% each.

Specimen 43: Augite andesite from NW¼ projected sec. 11, T13N, R8E along the Willame Creek logging road. This rock is from a sequence of interbedded volcanic graywacke and tuffaceous(?) sandstones. The upper contact of the flow is exposed, the lower contact is not.

Megascopic: The rock has a gray to gray-green aphanitic matrix and abundant large anhedral to euhedral plagioclase and pyroxene phenocrysts.

Microscopic: The matrix consists of small (average 0.08 mm.) sutured mineral grains, mainly plagioclase, pyroxene and possible quartz, and abundant small dust-sized magnetite(?) grains. The matrix has a cloudy aspect because of the abundance of fine-grained plagioclase grains most of which are altered to kaolin. The fine-grained material surrounds large (up to 3 mm.) euhedral phenocrysts of plagioclase and augite.

Plagioclase phenocrysts (20%) are An 45 in composition, and show kaolinitic alteration along very fine feather-like fractures. Most of the plagioclase crystals show albite and carlsbad twins, and some are zoned. The matrix plagioclase crystals (30%) are untwinned and irregularly shaped. Augite grains (20%) are mainly unaltered, although some are partially altered to magnetite and chlorite along their borders (pl. XXII , p. 94), and some are completely altered to chlorite and magnetite. The augite grains usually show twinning planes and commonly are euhedral in shape. Chlorite (10%) is a green fibrous variety which shows slight pleochroism. It is an alteration product of the matrix, and some of the pyroxene phenocrysts. Magnetite (5%) occurs as small discrete grains throughout the matrix, and some of the pyroxene phenocrysts are altered to magnetite in part. Quartz crystals (5%) are irregularly shaped and may be secondary in origin. Kaolin (5%) is an alteration product of the plagioclase grains. About 5%of the matrix consists of indeterminable fine-grained ma-

PLATE XXII

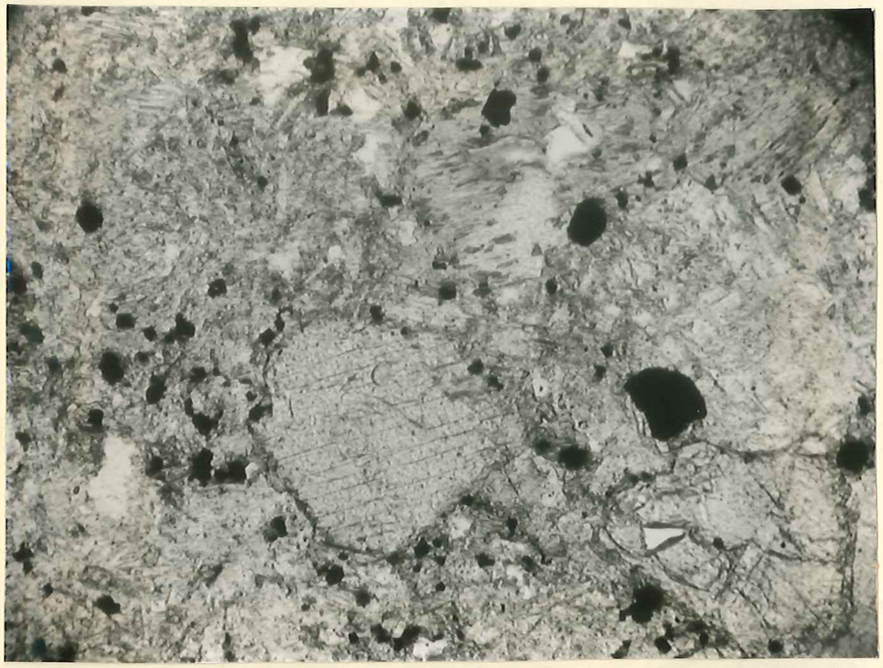


Figure 1. Specimen 43: Augite andesite, Keechelus Group. Typical Keechelus andesite. Note the extreme alteration of the feldspar grains. X 320, plain light.

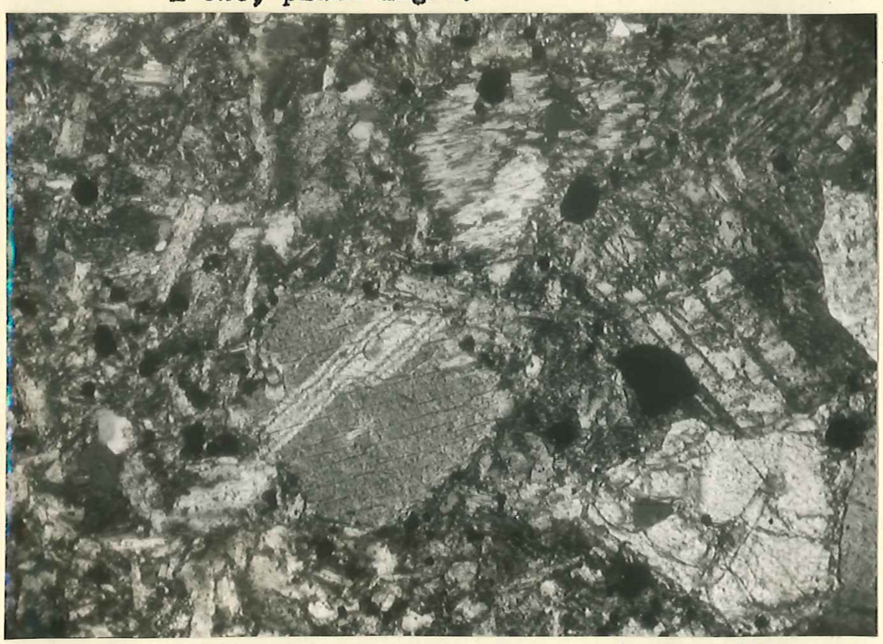


Figure 2. Specimen 43: Same view as above. Note twinned augite crystal. X 320, crossed nicols.

terial.

Specimen 44: Andesite from SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 31, T15N, R6E along an abandoned logging road overlooking the Nisqually River valley.

Megascopic: The rock is medium gray-green in color, contains indistinct feldspar phenocrysts, and highly irregular, dark green, altered ferro-magnesian(?) minerals.

Microscopic: The matrix contains abundant sub-microscopic minerals and isotropic glass(?). Also within the matrix are abundant irregular to well formed feldspar laths. Matrix feldspar is 60% and glass(?) is 15% of the rock.

Feldspar phenocrysts (15%), An 28 in composition, usually have ragged outlines and are mostly altered to kaolin along cleavage and fracture planes. Prehnite crystals (5%) occur in clumps within the matrix, and are often associated with a fibrous variety of chlorite (2%). Kaolin (3%) is an alteration product of the plagioclase. Magnetite (1%) is scattered throughout the matrix as dust-like material.

Specimen 45: Pyroxene andesite from NW$\frac{1}{4}$ sec. 20, T12N, R5E along State Highway 5.

Megascopic: The rock is a medium gray-green, aphanitic andesite containing small gray plagioclase phenocrysts.

Microscopic: The rock has a pilotaxitic texture and is micro-granular. Plagioclase grains (An 45) are 65% of the rock; 20% are phenocrysts, and 45% are matrix feldspars. Many of the phenocrysts are zoned and some are poikilitic in texture. Pyroxene crystals (20%) are very fine-grained equant grains, some of which are altered to chloritic material. Magnetite crystals (10%) are abundantly disseminated throughout the matrix. Chlorite (5%) is an alteration product of pyroxene grains. Some of the chlorite occurs within the fine-grained crystalline matrix.

Specimen 46: Augite basalt from NE$\frac{1}{4}$ sec. 15, T14N, R7E on an abandoned logging road about one mile north-west of Lake Tannamus.

Megascopic: The rock has a dark gray matrix, abundant anhedral and euhedral plagioclase and scattered pyroxene phenocrysts. The rock is very similar megascopically to many of the andesites.

Microscopic: The matrix contains indistinct plagioclase(?) grains, scattered magnetite, and some green chlorite and devitrified glass.

Feldspar grains (An 55) comprise about 30% of the rock, both as phenocrysts and as small matrix grains, many of which are altered to kaolin and some sericite. Augite (15%) occurs as euhedral grains, much of which is twinned. Chlorite (20%) is an alteration product of matrix material and of pyroxene grains. Magnetite (3%) consists of small specks throughout the matrix. In places, larger magnetite crystals occur in association with chlorite as an alteration product of augite (pl. XXIII,p. 97).

Specimen 47: Dacite(?) from SE¼ projected sec. 3, T13N, R8E along a logging road on Willame Creek.

Megascopic: The rock is a light blue-green to light blue-gray, aphanitic felsite. Parts of the rock are clastic in appearance, which is probably due to weathering around the mineral grains.

Microscopic: The matrix (30%) consists of devitrified glass(?), and contains abundant grains of quartz(?). Much of the matrix is altered to kaolin.

Plagioclase grains (25%) are matrix grains (20%), and a few small phenocrysts (5%). Phenocrysts are composed of oligoclase. Calcite (15%) and kaolin (30%) are alteration products of the feldspars. Magnetite grains occur as a few small scattered grains in the matrix. There are no ferromagnesian minerals nor chloritic alteration products.

Dacite was also found in SW¼ sec. 13, T14N, R6E, in NE¼ sec. 17, T14N, R6E, and in SE¼ sec. 1, T14N, R5E. All of the dacite rocks are remarkably free of ferro-magnesian minerals.

Arkosic Sandstone

Muscovite-bearing arkoses interpreted to be tongues of the Puget Group occur in a few places within member A. One tongue occurs along a logging road on North Fork Mineral Creek in E½ sec. 21, T14N, R5E. It is conformable with an overlying, massive clastic-volcanic breccia and has been faulted against a black basalt. This sandstone may be equivalent to the third Puget tongue exposed on Osborne Mountain (pp. 35-36), but cannot be correlated with certainty because

PLATE XXIII

Specimen 46: Augite basalt, Keechelus Group. Photograph shows magnetite rimmed, euhedral augite grain. X 520, plain light.

of an unconformable cover of post-Keechelus flows. The arkose is well sorted, light gray in color, is massive, has some carbonaceous layers, and contains muscovite. Lithologically it is similar to the Puget rocks exposed in the Nisqually River district. It contains 40% quartz grains (mostly strained), 1% plagioclase grains (An 33), about 2% muscovite flakes, and 5% chert fragments. Calcite cement makes up about 19% of the matrix.

Arkose also occurs along Mineral Creek in SW¼ sec. 10, T13N, R6E. It is fairly well sorted, is coarse- to medium-grained, is friable and massive, contains about 60% sub- to well-rounded quartz grains, has much well rounded feldspar grains (30%), 2% muscovite, and about 1% fine-grained black minerals (magnetite?). It is unusual since it contains a conglomerate lens with volcanic cobbles up to 4 inches in diameter. It is probably a reworked part of the Puget Group as indicated by (1) a greater amount of quartz than most sandstones of the Puget Group, and (2) the presence of a volcanic conglomerate lens.

<u>Member B</u>

Member B, about 10% of the surface exposures of the Keechelus Group, consists of over 5400 feet of homoclinally eastward dipping volcanic graywackes, breccias, conglomerates and fine-grained shales (pl. XXIV, p. 99). Member B occurs near the eastern border of the area. It overlies member A conformably, and disconformably underlies the upper Keechelus Group, and may thin westward, for no group of graywackes of comparable thickness has been found to the west.

The graywackes of member B occur in limited exposures along the southernmost part of Skate Creek road, are abundantly exposed along the Willame Creek logging road, and at one place near Johnson Creek.

Contacts

The upper contact of member B, on the basis of the map pattern, is interpreted as disconformable and as being overlapped northward by the overlying upper Keechelus volcanic flows. The lower contact appears to be conformable with the underlying member A, but no actual contacts were seen.

Extent and Correlation

Member B, along with the overlying and underlying units, forms the eastern limb of the Skate Creek anticline. Rocks similar to rocks of member B are interbedded with volcanic breccias in a few places south of the Cowlitz River, and may be a part of a series of coal bearing rocks south of Packwood. The rocks of member B cannot be traced north of Johnson Creek, but they may be equivalent to the sedimentary rocks which are considered to be part of the Puget Group that are exposed on the south side of Mount Rainier near Paradise (Coombs, 1936, geologic map).

Lithology

The rocks of this member consist of volcanic graywackes, volcanic conglomerates and shales. The prevailing color of the rocks is green-gray, but they are also gray and brown. The brown color is due mainly to weathering of the matrix material. Black carbonaceous shales are sometimes interbedded with rocks of member B.

The following rock descriptions are of typical graywacke specimens from member B.

Specimen 55: Volcanic graywacke from NW$\frac{1}{4}$ sec. 18, T13N, R9E.

Megascopic: The rock is a dark green, poorly sorted, very coarse-grained volcanic graywacke with some scattered rounded andesite pebbles as much as 7 mm. in size.

Microscopic: Fragments are 80%, and matrix material is 20% of the rock.

Rock fragments compose 50% of the rock and are of about six different types. The largest and most numerous fragments are porphyritic andesites, one of which is very light in color, and has abundant magnetite dust and a matrix of ragged feldspar laths and glass(?). Plagioclase phenocrysts of this fragment are An 35 in composition, and many show carlsbad and albite twinning planes. A few of the smaller rock fragments are rounded and have a dirty brown matrix with pilotaxitic texture. Another fragment type has irregular shapes, is reddish in color (matrix altered to hematite), has a felty texture and contains abundant twinned feldspar phenocrysts (An 45). Most of these phenocrysts are fresh, but some are slightly altered to kaolin.

Mineral fragments are 30% of the rock. Plagioclase grains (25%) vary in composition from An 27, and An 47 to An 60. They are mostly fresh, but some are somewhat altered to kaolin. Most of them are angular in shape, but some have sharp euhedral outlines. Unaltered pyroxene grains are 1%, leucoxene is 1%, and magnetite is 1% of the rock. Unidentified minerals are 1%, and one epidote grain was observed.

Specimen 56: Volcanic graywacke from NE$\frac{1}{4}$ projected sec. 2, T13N, R8E along a tributary of Willame Creek.

Megascopic: The specimen is from an outcrop of poorly sorted pebbly graywacke to sandy volcanic conglomerate, and contains pebbles as much as 25 mm. in size composed of light gray andesite, greenish-gray aphanitic andesite, and some greenish graywacke(?) pebbles. The overall color of the rock is gray-green.

Microscopic: Fragments compose 85%, and matrix material 15% of the rock. The matrix contains some former open(?) spaces that are now filled with zeolite minerals, and most of the fragments are surrounded by a yellow-brown, and sometimes greenish chloritic(?) substance. There are a few small grains (averaging about 0.04 mm. in size). Many of the larger fragments touch and are not surrounded by the matrix, but field evidence indicates that they are not agglutinated.

About 60% of the rock is composed of andesite rock fragments. There are about six different types, the largest fragment exceeding 4 mm. in size. Most of the fragments have very fine-grained to glassy unaltered matrices, and most have either feldspar and/or augite phenocrysts. Plagioclase is often slightly altered to kaolin, and some have chlorite in their centers that is probably the alteration product of former ferro-magnesian inclusions. Pyroxene grains are generally fresh, but a few are slightly altered to chlorite along their borders and in cracks. Magnetite grains are scattered throughout some of the rock fragments, but are generally not abundant. Some of the smaller rock fragments are holocrystalline and have equant grains, and possibly are derived from eroded dikes or sills. All the observed fragments are andesite, none of which are vesicular.

Mineral fragments compose 35% of the rock. Andesine crystals (8%) generally are untwinned, and some are slightly altered to kaolin. Augite (5%) is angular to rounded in shape, some are euhedral, and most are fresh in appearance. Chlorite(?) forms 10% of the rock and occurs within the matrix, and as an alteration product of ferromagnesian minerals. Magnetite grains (2%) are disseminated within the matrix, and along the borders of some of the pyroxene crystals.

Specimen 57: A fine-grained volcanic graywacke from SW¼ sec. 8, T13N, R9E near Skate Creek along Willame Creek logging road. This locality is the same as leaf locality WA 235. The rock is from a well bedded sequence of graywackes and shales containing carbonaceous material.

Megascopic: The rock is dark to medium gray-green in color, is very fine-grained and is well sorted.

Microscopic: The rock contains grains which average about 0.08 mm. in size. Rock and mineral fragments comprise 90%, and matrix material, which averages about 0.0002 mm. in size, comprises 10% of the rock.

The matrix is composed of small discrete grains often difficult to distinguish from aphanitic rock fragments, and is often altered to a greenish chlorite(?). All the fragments are angular, and many touch thereby excluding the surrounding matrix.

Abundant carbonaceous stringers, oriented parallel to the bedding, give the rock its dark color. Matrix fragments are generally too small to identify, but appear to be mineral grains.

Approximately 75% of the specimen appears to be small rock fragments apparently all of the same type. They have glassy(?) matrices and some have very small feldspar laths. They are difficult to distinguish from the matrix.

Feldspar grains are all very fresh and are angular in shape. Compositions of plagioclase grains range from An 28 to An 58, with the majority being in the andesine range. Leucoxene(?) grains are approximately 5% of the rock and occur as very small grains throughout the rock. Two grains of cliachite(?) were observed.

<u>Specimen 58</u>: A volcanic graywacke from SW¼ sec. 8, T13N, R9E near the location of specimen 57.

<u>Megascopic</u>: The rock is a light green to light gray-green, fairly well sorted, fine- to medium-grained, well indurated volcanic graywacke with a rough conchoidal fracture. Carbonaceous fragments occur in the rock.

<u>Microscopic</u>: The rock is very similar to specimen 57, but the rock and mineral fragments are larger in size. Feldspar grains are of the same compositions, and the rock fragments are easier to see in specimen 58 than in specimen 57 (pl. XXV , p. 104). The matrix is composed of very fine-grained, nearly isotropic argillaceous(?) matter.

The rock is about 90% angular to rounded rock and mineral grains, and 10% matrix material. Rock fragments (60%) are of about six different types; one type is amygdaloidal, some are holocrystalline with equant grains (dike material?), some are porphyritic, and some are aphanitic in texture. Almost all the rock fragments show some alteration to chlorite.

Primary and secondary mineral fragments form about 30% of the rock. Plagioclase grains (10%) are mainly euhedral and twinned, and some show zoning. There is 15% chlorite, 5%leucoxene(?) and 0.1% chliachite. Three grains of amphibole and one grain of pyroxene were observed.

PLATE XXV

Specimen 58: Volcanic graywacke, Keechelus Group. Photograph shows clastic texture of the rock.
X 320, plain light.

Upper Keechelus Group

Rocks included within the upper Keechelus are tuffs, lapilli-tuffs, tuffaceous sandstones and siltstones (Oligocene?) which occur in S½ sec. 19, T14N, R7E, and all the rocks which overlie them in the Silver Creek depression (pp. 139); and volcanic flows which crop out on the eastern border of the area that unconformably overlie members A and B of the middle Keechelus. Upper Keechelus rocks may be as much as 5000 feet in thickness in the Silver Creek depression.

The tuffaceous rocks, which occur in limited outcrop near Catt Creek, are lithologically dissimilar to most of the lower and middle Keechelus rocks, and appear to be unconformable above a south dipping series of typically green Keechelus breccias along Catt Creek. Leaves from the tuffs are tentatively dated as Oligocene on the basis of one maple seed fragment, Acer glabroides (Brown, 1955, written communication). Although these rocks crop out in a limited area, the regional structural pattern suggests that tuffaceous(?) sediments which are found in secs. 13, 14, 22 and 23, T13N, R7E in the Silver Creek region may also be Oligocene(?) in age.

The following petrographic description is of a tuff from near Catt Creek.

Specimen 41: Tuff from SW¼ sec. 19, T14N, R7E along a tributary of Catt Creek.

Megascopic: A light tan colored, fine-grained rock containing light colored rock and mineral fragments, and carbonaceous matter which are crudely oriented parallel to the bedding planes.

Microscopic: The matrix (60%) is composed of undetermined submicroscopic birefringent fragments. Secondary c alcite grains (30%) occur as irregularly shaped crystals which surround and include the matrix material. Some of the calcite is an alteration product of plagioclase(?) grains. Angular glass fragments (9%), some of which are partially recrystallized, are mainly elongate in shape. Many of the glass fragments are oriented parallel to each other (pl. XXVI, p. 107). Small angular quartz fragments are about 0.1% of the rock.

The volcanic flows that occur along the eastern border of the area total more than 2000 feet in thickness. The map pattern (pl. XXXVI, p. 154) suggests that the contact between the flows and the underlying middle Keechelus rocks is disconformable, although the contact was not observed. These rocks consist of dark gray to light brown and gray, partially altered, crudely columnar andesite flows. They crop out extensively from near Johnson Creek to the mouth of Skate Creek, and may extend into Mount Rainier National Park to the north. Near Willame Creek, columnar andesites form a spectacular 500 to 600 foot cliff.

This series of flows is included within the Oligocene(?) upper Keechelus because structure sections across the area suggest their equivalence to volcanic flows in the Silver Creek depression which lie stratigraphically above the light colored Oligocene(?) tuffs exposed near Catt Creek. This correlation, however, cannot be proved.

The following are petrographic descriptions of two rock samples from the volcanic flows that crop out east of Skate Creek.

<u>Specimen 53</u>: An andesite specimen from W½ projected sec. 22, T14N, R8E, near the junction of Johnson and Skate Creeks. In outcrop, the flow shows crude columnar jointing and blocky jointing. Near the center of the flow there is

PLATE XXVI

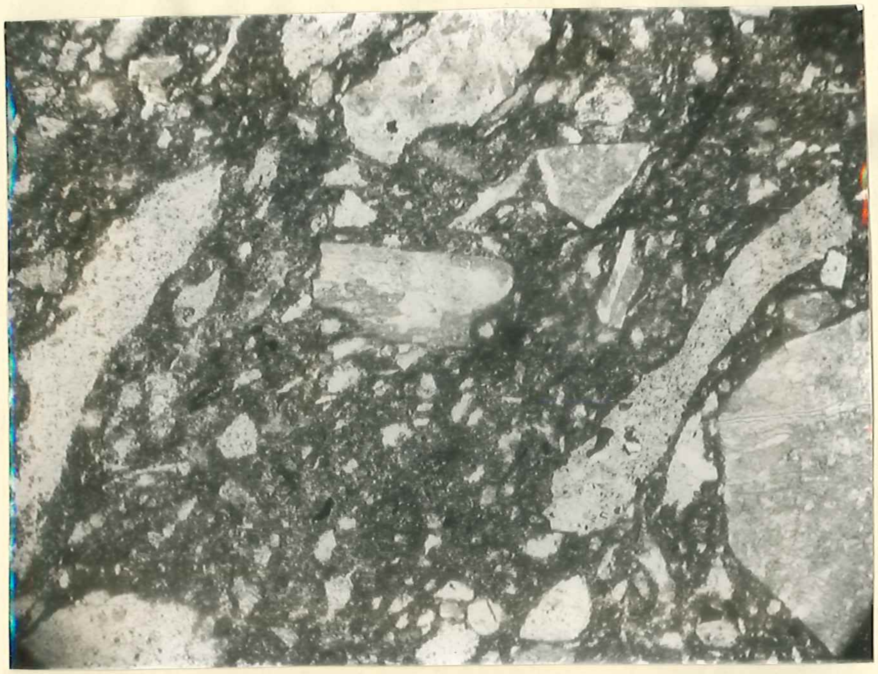


Figure 1. Specimen 41: Tuff, Keechelus Group. Note parallelism of large glass fragments. X 320, plain light.

Figure 2. Same view as above. X320, crossed nicols.

platy jointing.

<u>Megascopic</u>: A reddish-gray to reddish-brown porphyritic andesite.

<u>Microscopic</u>: The matrix is composed of very weakly birefringent irregularly shaped minerals and nonbirefringent material (glass?). Abundant small feldspar crystals, and some small ferro-magnesian (augite?) minerals which are altered to antigorite and chlorite, occur in the matrix. Plagioclase phenocrysts (An 30) have a ragged appearance, although most show zoning and albite twinning planes. Many of the feldspar grains are partially altered to sericite and kaolin. Augite crystals are in various stages of alteration to antigorite and chlorite; some are completely altered. Magnetite is present as scattered specks. Plate XXVII (p. 109) a cluster of augite and feldspar crystals.

<u>Specimen 54</u>: Andesite from NE¼ projected sec. 21, T14N, R8E near the junction of Skate Creek and Johnson Creek.

The rock is very similar to specimen 53, but the feldspar phenocrysts show more fracturing, and the matrix is composed of dark brown, nonbirefringent glass. This rock also contains vesicles, while specimen 53 does not.

Age of the Keechelus Group

General Statement

The Keechelus Group is similar lithologically to lower Tertiary volcanic rocks found throughout the Cascades in Oregon and Washington. If correlations are based entirely upon lithology, its age spans Eocene and Oligocene time. Establishing a definite time horizon within the volcanic rocks of this vast region is virtually impossible, however, because of the recurrence of similar rock types throughout the lower Tertiary and because of the uncertainties of age determinations by fossil leaves.

Evidence from the studied area shows that deposition of Keechelus rocks began in the middle(?) or upper part of the Eocene epoch, and continued into Oligocene(?) time. The uppermost part of the Keechelus

PLATE XXVII

Specimen 53: Andesite, Keechelus Group. Cluster of augite and plagioclase grains. X 240, plain light.

Group is apparently not exposed in the Elbe-Packwood area, therefore the upper age limit cannot be designated.

Previous Literature

Smith and Calkins (1906, p. 8) assigned Keechelus rocks to the Miocene because of its unconformable superposition on the Paleocene Swauk formation, lower to middle Eocene Teannaway Basalt, and the Guye formation in the northern part of the Snoqualmie quadrangle, and because of its position below the middle Miocene Yakima Basalt and the overlying Pliocene Ellensburg formation in the southern part of the quadrangle. The Guye formation at that time was thought to be Miocene on the basis of four fossil leaves, although stratigraphic evidence indicated a pre-Miocene age. It has since been shown to be Eocene in age, probably upper Eocene (Warren, 1941, p. 811).

Warren (1941, pp. 810-811) considered the Keechelus to be Oligocene in age because of its position between the Eocene Guye formation and the pre-Yakima basalt and supposedly earlier Miocene Fifes Peak formation. The Fifes Peak formation is regarded as Miocene by Warren because it lies beneath the middle Miocene Yakima basalt.

In 1941, Grant (p. 591) discovered an Oreodont jaw in the Keechelus rocks near the Tieton Reservoir. It was identified by R. A. Stirton of the University of California as the lower jaw of a young Eporeodon which occurs in the John Day formation of Oregon. The range of Eporeodon is middle Oligocene to lower Miocene (Thorpe, 1932, p. 65). Grant therefore has given proof that at least part of the Keechelus Group is post-Eocene in age.

Abbott (1953, p. 46) agrees with Warren that the Keechelus is Oligocene, but believes that the lower part of the Keechelus may intertongue with upper Eocene Puget rocks in Upper Bumping River.

In a general discussion of the volcanics of the Cascade Mountains, Waters (1955, p. 710) suggests that andesitic volcanism began in Eocene time, because andesitic debris is found in Eocene sedimentary rocks adjacent to the Cascades.

Present Area

The Keechelus Group of the present area is upper Eocene and may extend into the Oligocene(?) epoch. Its lower part might be as old as middle(?) Eocene.

Fossil leaves have been collected by the writer and by Roland Brown of the U.S. National Museum, and are listed separately although some collections were made from the same locality. All the leaves have been identified by Brown.

The following leaf fossils were collected from member B of the middle Keechelus near Packwood along Skate Creek.

<u>University of Washington Locality WA 235</u>: SW$\frac{1}{4}$ sec. 8, T13N, R9E.

<u>Castanea castaneaefolia</u> (Unger) Knowlton (No. 13710)

<u>Metasequoia occidentalis</u> (Newberry) Chaney (No. 13711)

<u>Glyptostrobus dakotensis</u> Brown (No. 13712)

<u>Laurus</u> sp. (No. 13713)

<u>U.S. Geological Survey Packwood Locality</u> (same locality as above).

<u>Adiantum anastomosum</u> Brown

Cercidiphyllum elongatum Brown

Dillenites sp.

Platanus sp.

Sequoia affinis Lesquereux

According to Brown (1955, written communication), these specimens are similar to those at Steel's Crossing which are dated as late Eocene. Significantly, the rocks in which the leaves occur apparently are several hundred feet stratigraphically above the uppermost Puget tongue in the Nisqually River district.

The fossils listed below are from member A of the middle Keechelus Group, about 5500 feet stratigraphically above the uppermost tongue of Puget rocks on Osborne Mountain. These fossils are "apparently late Eocene" in age (Brown, 1955, written communication).

U.S. Geological Survey Catt Creek Locality: SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 13, T14N, R6E.

Lastrea fischeri Heer

Metasequoia occidentalis (Newberry) Chaney

Carya sp.

Salix sp.

Comptonia sp.

Betula sp.

Alnus sp.

Calyptranthes sp.

Persea sp.

The Oligocene(?) dating of the upper Keechelus is based upon the fossil leaves listed below.

U.S. Geological Survey "Creaking Tree" Locality: SE$\frac{1}{4}$ sec. 19, T14N, R7E.

Metasequoia occidentalis (Newberry) Chaney

Cercidiphyllum sp.

Betula sp.

Persea sp.

Ulmus sp.

Acer glabroides Brown

The rocks at the "Creeking Tree" locality are light colored tuffaceous rocks which are lithologically unlike most of the Keechelus rocks in this area. Because of their structural attitude they appear to be unconformable on the underlying rocks, although the contact was not seen. Brown states, "The presence of Acer glabroides in this collection, as well as the general composition of the collection, is suggestive of Oligocene age". The age assignment is very tentative, although it is significant that the Oligocene dating was made without the knowledge of the lithologic or general structural relationships.

Correlation of the Keechelus Group

Keechelus rocks can be traced eastward through Mount Rainier National Park from the present area to the Mt. Aix quadrangle where they disappear beneath the Columbia River Basalts. They have been traced northward by Coombs from Mount Rainier National Park to the type area of the Keechelus volcanics (Coombs, 1936, p. 150). Warren

(1945) believes that Keechelus rocks crop out extensively east and southeast of Seattle in King County.

About 15 miles west of the Elbe-Packwood area, Snavely (1951) has mapped a large region in the Centralia-Chehalis area that includes the middle Eocene Northcraft formation. The Northcraft formation, similar lithologically to the Keechelus Group, is correlated by Snavely to the Keechelus. The writer, however, believes that the Northcraft formation is older than the Keechelus Group, although the Northcraft may be a lower tongue of the Keechelus, and equivalent to the Older Volcanics exposed in the Nisqually River district (pl. II, p. 7).

Only two papers have been published that deal partially with the stratigraphy south of the Elbe-Packwood area in the Washington Cascade Mountains. Near Mount St. Helens, Verhoogen (1937) has observed that rocks similar to those of the Keechelus Group lie above Eocene sedimentary rocks, but offers no proof for the Eocene dating of the sedimentary rocks. Near the Columbia River in Skamania county, Feltz (1939, pp. 297-316) has described a granodiorite stock that intrudes the Eagle Creek formation and the lower Skamania andesites. The Eagle Creek formation is lithologically similar to the Keechelus Group, containing varicolored volcanic tuffs and breccias, conglomerates, and minor amounts of intercalated andesite flows. Feltz mentions that the tuffs and breccias have been reworked and deposited by ancient streams. He considers the Eagle Creek formation to be Oligocene in age on the basis of fossil leaves. The lower Skamania andesites lie above the

Eagle Creek formation with a disconformable to angular-unconformable relationship. This formation, lithologically very similar to the Fifes Peak andesite described by Abbott, is composed of a thick series of gray and greenish-gray, dominantly porphyritic andesites with some columnar jointing, and minor amounts of intercalated pyroclastics.

It is believed that the Eagle Creek formation is, at least in part, equivalent to the Keechelus Group because of (1) the lithologic similarity of the Eagle Creek formation to the Keechelus Group of the Elbe-Packwood area, and (2) the structural similarity between the Keechelus-Fifes Peak contact in the Mt. Aix quadrangle and the Eagle Creek-lower Skamania contact of Feltz' area.

YOUNGER VOLCANICS

General Statement

The name Younger Volcanics is used by the writer for a group of unaltered to slightly altered gray, brown, red and black basalts, felsites and volcanic breccias exposed in the northwest corner of the mapped area near Elbe and Mineral. This series of rocks, about 15% of the Elbe-Packwood area, extends several miles to the north and northwest of the northern boundary. The Younger Volcanics are generally flat-lying, although north of Elbe they have a slight northeast dip. Differences in elevation of the presumed contact of the Younger Volcanics with underlying rocks (about 3000 feet), indicate that the Younger Volcanics were extruded onto a region of high relief.

Rocks similar to those of the Younger Volcanics are found in several places within member A of the Keechelus Group, but it is not certain whether these rocks are part of the Keechelus Group or are eroded remnants of the Younger Volcanics.

Contacts

The contact between the Younger Volcanics and the underlying rocks was not seen, but because of their probable low dips, the Younger Volcanics are believed to be unconformable on the older folded rocks. About two and one-half miles west of Mineral (SW$\frac{1}{4}$ sec. 6, T14N, R5E) is an outcrop of volcanic flows considered to be part of the Younger Volcanics. These flows may overlie the Puget Group, but the contact relations are obscure. The contact at this place may be a fault.

The upper part of the Younger Volcanics is apparently not exposed in the mapped area.

Lithology

The rocks are mainly hypersthene basalts, possibly some andesites, trachyte and rhyolite(?). Volcanic breccias, agglomerates and tuffaceous rocks were also observed along a logging road north of Elbe. The flows are mainly black in color, but are also light to dark gray, brown, and in places weather to a reddish-brown color. Columnar jointing occurs in basalt at Sach's Corner in Elbe, and near the mouth of Mineral Creek about two miles east of Mineral. Other columnar-jointed basalts and andesites similar to rocks of the Younger Volcanics are associated with parts of the middle Keechelus Group, but cannot be differentiated from the Keechelus rocks.

Petrographic Description

Specimen 59: Hypersthene basalt from C., sec. 8, T14N, R6E about two miles southwest of National along road to lookout.

Megascopic: A medium gray basalt containing dark-colored feldspar phenocrysts and some pyroxene phenocrysts.

Microscopic: The rock has an intergranular ophitic texture. The matrix contains some glass, but is mainly pyroxene grains. Plagioclase grains are about 60% of the rock, about 20% of which are phenocrysts and 40% are matrix crystals. Both the matrix and phenocryst feldspars are fresh, and are about An 60 in composition. Pyroxene grains are about 35% (20% Augite and 5% hypersthene) of the rock, none of which are altered. Chlorite is about 2% of the rock, and may be an alteration product of hypersthene. The rock is much fresher than any of the observed Keechelus rocks.

Specimen 60: Hypersthene basalt from S½ sec. 5, T14N, R6E about two miles southwest of National along road to lookout.

Megascopic: Black platy basalt containing dark-colored feldspar phenocrysts and conspicuous pyroxene phenocrysts.

Microscopic: The matrix texture is pilotaxitic to felty and contains abundant tiny pyroxene grains, feldspar laths, some magnetite and some glassy material. Feldspar (An 60) is about 50% of the rock, 40% of which is matrix feldspar, and 10% are phenocrysts. Well twinned euhedral augite grains are 5% of the rock, and in places form rims around hypersthene grains (5%). Fine-grained pyroxene crystals in the matrix are 10% of the rock. Secondary minerals include pennine (1%) and antigorite (2%).

Specimen 63: Hypersthene basalt from Sach's Corner at the junction of the southbound and eastbound branches of State Highway 5 at Elbe.

Megascopic: The rock is a dark gray to black porphyritic basalt. It is fresh and crops out in vertical columns.

Microscopic: The matrix, 70% of the rock, is composed dominantly of brown colored glass, some tiny plagioclase laths, magnetite and unidentified, weakly birefringent minerals. Imbedded in the matrix are feldspar phenocrysts (20%) which are fresh, euhedral in shape, have albite twinning planes and occasionally are zoned. Some of the plagioclase phenocrysts occur in clusters (glomerophyric). These phenocrysts are An 60 in composition, and grade in size to the small lath-shaped feldspar crystals of the matrix (seriate texture). Augite (5%) and hypersthene (5%) occur as unaltered phenocrysts (pl. XXXVIII, p. 119).

Specimen 64: Trachyte from road metal quarry in E½ sec. 11, T14N, R5E, about 2½ miles east of Mineral on the eastern flank of Roundtop Mountain.

Megascopic: The rock is light tan to white in color, is aphanitic and has mottled brown weathering spots, and a few very small vesicles.

Microscopic: The rock has a felty-feathery texture. The matrix (80%) is composed primarily of irregularly shaped feldspar crystals and microlites, and possibly some interstitial glass. Sanidine comprises 5% of the rock as irregularly shaped, unaltered microphenocrysts (pl. XXIX, p. 120). Untwinned plagioclase grains (1%) of probable oligoclase composition occur as microphenocrysts along with the sanidine. About 30% of the matrix is composed of kaolin which has altered from matrix feldspar. Hematite (1 0%) occurs in the matrix as an alteration product of magnetite. Magnetite is 1% of the rock. Small unidentified brown mineral flakes (1%) occur as an alteration product of sanidine. Small vesicles comprise 2% of the rock.

On the drainage divide between Mineral Creek and North Fork Mineral Creek in NW¼ sec. 29, T14N, R6E are outcrops of basalt which are believed to be part of the Younger Volcanics because of their composition. The following petrographic description is of a specimen from

PLATE XXVIII

Specimen 63: Hypersthene basalt, Younger Volcanics. Microphenocrysts of plagioclase are crudely parallel. Hypersthene grain is in lower right hand corner. X 400, plain light.

PLATE XXIX

Specimen 64: Trachyte, Younger Volcanics. Sanidine (S) microphenocrysts show irregular borders.
X 320, plain light.

from one of these basalt outcrops.

<u>Specimen 61</u>: Hypersthene basalt from NW$\frac{1}{4}$ sec. 29, T14N, R6E.
<u>Megascopic</u>: The rock is dark gray to black in color with abundant, small, milky white feldspar phenocrysts.
<u>Microscopic</u>: The matrix is heavily charged with magnetite, and contains small feldspar laths and glass. About 85% of the rock is composed of plagioclase grains (An 60) which are very little altered. They are usually unzoned, although some of the feldspar grains show zones which are outlined by secondary sericite(?). Some of the feldspars show resorption along their borders. Hypersthene is about 15% of the rock. Chlorite is about 0.5%of the rock.

Volcanic rocks similar in megascopic appearance to the Younger Volcanics occur in several places within the Elbe-Packwood area, and may indicate that the entire area was once completely or partially covered by the Younger Volcanics. However, many of these outcrops of volcanic rocks may be parts of small dikes and/or sills which intrude the Keechelus Group.

Age and Correlation

The age of the Younger Volcanics cannot be determined with certainty, but the unaltered appearance and the presence of hypersthene in almost all these rocks suggests a close petrogenetic relationship to the hypersthene bearing Mount Rainier flows described by Coombs (1936, p. 182). Mount Rainier was probably formed during Pleistocene time (Coombs, 1936, p. 174), but there may have been an earlier, now destroyed cone related to the Younger Volcanics. Verhoogen (1937, p. 395) states that previous to the building of Mount St. Helens, a large volcano may have been formed in post-Miocene time. This earlier volcanic activity may have been related in time to the Younger Volcanics.

The time of formation of the Younger Volcanics is pre-glacial and pre-Mount Rainier. The most likely time of extrusion is late Pliocene, and, although petrographically different, the Younger Volcanics may be contemporaneous with the hypersthene bearing Pliocene(?) Deep Creek Andesite described by Abbott in the Mt. Aix quadrangle (1953, pp. 116-126).

I N T R U S I V E   I G N E O U S   R O C K S

GENERAL STATEMENT

Dikes and sills which are basic to acidic in composition intrude the rocks of the Puget and Keechelus Groups. It is difficult to estimate the extent of the intrusions because of poor exposures. Occasionally small intrusive bodies can be seen within a single outcrop, and large intrusive bodies have been recognized on the basis of their relatively coarse-grained holocrystalline textures.

INTRUSIVE ROCKS IN THE PUGET GROUP

Nisqually River District

In the Nisqually River district, two sills(?), each about one foot thick, and one andesite dike are known to intrude the lower Puget tongue.

The sills(?) occur in a small outcrop in SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22, T15N, R6E. They are separated from each other by a thin bed of lignitic coal, and both show columnar jointing. The following are petrographic descriptions of specimens from these sills(?).

> Specimen 5: Basalt, the lower of two, one-foot sills(?) found about one mile north of Ashford in SW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22, T15N, R6E, near the upper contact of the lower Puget tongue.
>
> Megascopic: A dark gray to black, slightly porphyritic basalt.
>
> Microscopic: The rock has a felty texture and a matrix (30%) composed of devitrified glass, calcite and chloritic matter. Plagioclase grains (An 56) comprise 40% of the rock; 35% are matrix grains, and 5% are phenocrysts. The largest plagioclase phenocryst is glomerophyric and is 1.6 mm. in longest dimension. Some plagioclase grains are altered to kaolin (5%), but most are fresh. Chlorite (10%) is secondary pennine, and is altered from pyroxene(?). Calcite (20%) replaces the matrix and parts of the feldspar crystals. Magnetite grains (3%) are disseminated throughout the rock.

Specimen 6: Andesite(?), the upper of two, one-foot sills(?) at the same locality as specimen 5.

Megascopic: A medium gray to buff andesite(?) with conspicuous milky feldspar phenocrysts.

Microscopic: The composition of the rock is not known because of the extreme alteration of the feldspars, but has the appearance of andesite. The rock contains some vesicles filled with zeolite minerals. The feldspar and ferro-magnesian minerals have been completely altered to calcite and chlorite.

The following is a petrographic description of a specimen from the andesite dike.

Specimen 7: Andesite from a 15(?) foot dike in NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 22, T15N, R6E about 1$\frac{1}{2}$ miles northwest of Ashford. The attitude of the dike is N80E 75SE and cuts interbedded sandstone and shale which have an attitude of N46E 12SE.

Megascopic: The rock is a dark gray porphyritic andesite of the same general megascopic appearance as specimen 5 (p. 123).

Microscopic: The matrix is composed of devitrified glass(?) that is altered to chloritic matter, calcite, and quartz crystals. Plagioclase grains (An 45) comprise about 55% of the rock; 25% are phenocrysts, and 30% are matrix feldspars. The phenocrysts are mainly fresh. The matrix feldspar has highly irregular shapes which suggest a late stage of crystallization. Chlorite (15%) is an alteration product of the matrix material and former pyroxene crystals.

A dike(?) that intrudes rocks of the upper Puget tongue (S$\frac{1}{2}$ NW$\frac{1}{4}$ sec. 17, T15N, R7E), is a coarse-grained andesite porphyry similar in composition to many of the Keechelus flows, and contains 60% plagioclase (An 29), 5% quartz and 25% highly altered pyroxene crystals.

Tilton River District

The Puget Group of the Tilton River district contains numerous igneous bodies, some of which are definitely intrusions. Culver (1919, p. 109) mentions the abundance of igneous rocks in this region, and considers the majority of them to be dikes and sills. Mackin (1944, pp. 7, 9, 16), in a detailed study of the cinnabar workings east of Mineral, found that the sedimentary rocks are intruded by basic sills and dikes. He describes one intrusion as a diabasic lopolith, and another as a diabasic laccolith.

In NE$\frac{1}{4}$ sec. 35, T13N, R4E along State Highway 5 one mile north of Morton is a well exposed outcrop of diabase, probably of intrusive origin. It may be equivalent to one of the intrusions described by Mackin.

A well exposed six foot wide andesite dike occurs in a small quarry in SE$\frac{1}{4}$ sec. 34, T13N, R4E (pl. XXX, p. 126). It is undoubtedly of intrusive origin, and interestingly shows only a slight baking effect on the rocks it intrudes.

Two large intrusive bodies crop out in the northern part of the Tilton River district; one is a hypersthene gabbro dike(?), the other is a hypersthene diorite sill. Their probable space relationships are indicated on plate XXXVI (p. 154).

The hypersthene gabbro crops out near the western border of the area about 2$\frac{1}{2}$ miles west of Mineral, and is considered to be a dike on the basis of a persistent north-south line of outcrops of diabasic rocks. The northernmost outcrop is in NE$\frac{1}{4}$ sec. 12, T14N, R4E; the southernmost outcrop is in NE$\frac{1}{4}$ sec. 26, T14N, R4E. The dike(?) may continue as far south as N$\frac{1}{2}$ sec. 3, T13N, R4E, where another outcrop of diabase was found, but a correlation of 2$\frac{1}{2}$ miles without more control would be invalid. The minimum length of the dike(?) then is three miles, but it may be as much as six miles long. On the basis of a cross sec-

PLATE XXX

Andesite dike near the town of Morton. The dike intrudes Puget Group sandstones which show very slight baking effects. The sandstones strike N20E and dip 50° SW toward the reader. The dike strikes N35E, almost at right angles to the sandstone, and dips 55° NW. View is north.

tion drawn along DD' (pl. XXXVII, p. 155), it has a maximum width of 450 feet. It may be a sill rather than a dike, but apparently the intrusion cuts across minor structures in places. The following is a petrographic description of a typical sample of the dike(?).

> Specimen 30: Gabbro from NE$\frac{1}{4}$ sec. 26, T14N, R4E along the State Forest Service fire access road near East Creek.
>
> Megascopic: The rock is holocrystalline, medium-grained and black to dark gray in color, with an unusual abundance of milky to dark gray, euhedral plagioclase phenocrysts. Megascopically it is gabbro.
>
> Microscopic: The rock has a seriate texture due in large part to the fragmental nature of many of the feldspar and pyroxene crystals. The rock contains 60% plagioclase grains (An 54) often with cloudy inclusions which are parallel to zoning and twinning lines (pl. XXXI, p. 128). Pyroxene crystals form about 10% of the rock; 5% is augite and 5% is hypersthene. The accessory mineral apatite is very abundant (3%), and is commonly in the form of long euhedral needles that show well developed cleavage perpendicular to the long axes. Secondary chlorite(?) (25%) occurs as fracture fillings in all the other minerals, and as an alteration product of a former glassy(?) material which surrounds the feldspar and pyroxene crystals. Pyrophyllite(?) and perovskite(?) are very minor in amount. Microscopically the rock is hypersthene gabbro.

The spatial dimensions of the hypersthene diorite sill are poorly known. The northern extension of the sill is apparently faulted, and interpretation based upon structural pattern and topography. The sill disappears northward in SW$\frac{1}{4}$ sec. 7, T14N, R5E about two miles southwest of Mineral, and apparently extends southward to sec. 8, T13N, R5E where it changes strike from southwest to northeast(?) across the Tilton River anticline.

Anomalous attitudes found in SW$\frac{1}{4}$ sec. 29, T14N, R5E and in secs. 5 and 6, T13N, R5E near the base of the sill, may be caused by the in-

PLATE XXXI

Specimen 30: Gabbro, Tilton River district. Plagioclase (zoned), magnetite and augite. X 320, crossed nicols.

trusion.

The sill is composed of an equigranular, holocrystalline, medium- to fine-grained, light gray diorite, which, under the microscope is seen to contain hypersthene. The following is a petrographic description of a specimen of the sill collected near Summit Creek.

> <u>Specimen 31</u>: Diorite from NE$\frac{1}{4}$ sec. 30, T14N, R5E near Summit Creek along an abandoned logging road. The specimen was collected from near the stratigraphic base of the sill.
>
> <u>Megascopic</u>: The rock is a fine-grained, light to medium gray diorite.
>
> <u>Microscopic</u>: The rock contains 65% plagioclase (An 49) which has been mostly altered to kaolin. There are 10% augite, 10% hypersthene and 2% magnetite grains. A brownish-yellow alteration product (chlorite?) comprises about 10% of the rock. Needles of apatite comprise about 0.1%, and secondary quartz grains are 3% of the rock.

> <u>Specimen 32</u>: A diorite specimen from near the top of the sill in the vicinity of Summit Creek. It has about the same composition as specimen 31, but is more highly altered.

The contact between the sill and the overlying sedimentary rocks at Summit Creek is a 20 foot wide brecciated zone. Toward the top of the sill the diorite becomes darker and more altered, and passes into the brecciated contact zone. The rock above the contact is a very well indurated (probably baked) green sandstone. The fracturing and alteration near the top of the sill, and the apparent baking of the sandstone indicate an intrusive contact. The contact of the sill with the underlying rocks was not seen.

The above described diorite rocks are correlated with diorite which occurs along State Highway 5 in NW$\frac{1}{4}$ sec. 8, T13N, R5E. The following is a description of a rock from this outcrop.

Specimen 33: Diorite from NW$\frac{1}{4}$ sec. 8, T13N, R5E from a roadcut along State Highway 5.

Megascopic: The rock is light to medium gray and shows many poorly developed mafic crystals and abundant feldspar grains. It weathers to a dull brown color.

Microscopic: There are 80% plagioclase grains (An 45), many of which are zoned and show kaolinization along innumerable feather-like fractures. Augite and hypersthene crystals are 5% each, some of which are clear, and some of which show slight alteration to chlorite along their crystal boundaries. Chlorite, an alteration product of the pyroxenes, is approximately 0.1%, and secondary(?) quartz grains are 1% of the rock.

INTRUSIVE ROCKS IN THE KEECHELUS GROUP

In the Keechelus Group, two relatively large intrusions and several small intrusions have been recognized, although their aerial extents are poorly known.

One of the relatively large intrusions is a diorite sill which intrudes rocks of member A near Bertha May Lakes and Granite Lake. The sill apparently pinches out westward in NW$\frac{1}{4}$ sec. 16, T14N, R7E; its eastern end could not be located. It has apparently risen along a contact between volcanic graywacke and volcanic breccia, but the contact relations are obscure.

The diorite is similar in composition to most of the andesite flows and andesite breccias of the region, and may possibly be one of many feeders for andesitic materials younger than the Keechelus Group. Similar intrusive bodies have probably contributed extrusive materials to the Keechelus volcanic sequence.

The following is a petrographic description of a specimen of diorite from the sill near Lake Tannamus.

Specimen 48: Diorite from NE$\frac{1}{4}$ sec. 15, T14N, R7E along an abandoned logging road ½ mile northwest of Lake Tannumus. The rock is representative of the sill, although was found as float material.

Megascopic: Milky white plagioclase grains compose about one-half of the rock; dark colored ferro-magnesian minerals (pyroxene?) and finer-grained matrix material form the other half. The rock has a "salt and pepper" distribution of light and dark minerals. It is similar in appearance to the coarse-grained rocks described from the Tilton River district (pp. 127-130).

Microscopic: The rock is holocrystalline in texture and contains lath shaped plagioclase grains and ferromagnesian minerals. Plagioclase grains (An 48) comprise 70% of the rock, most of which show kaolinitic alteration along twinning planes and feather-like fractures. Some of the feldspar grains are completely fresh (pl. XXXII, p. 132). Augite crystals (5%) are mainly altered to a brown chloritic substance (20%). One grain of hypersthene was observed. Kaolin is 4% and secondary quartz grains are 1% of the rock. Apatite (0.1%) occurs sparingly.

A large dacite dike crops out in the headwaters of Willame Creek in E½ projected section 5, T13N, R8E. The dacite is a light blue-gray, sugary textured rock with large quartz and plagioclase phenocrysts, and altered biotite crystals. Two exposures of dacite which occur one mile apart are believed to be part of the same dike because the rocks have the same mineral compositions. The correlation of these two outcrops is across the structural trend. A description of two specimens from the Willame Creek dacite dike follows.

Specimen 49: Dacite from E½ projected sec. 5, T13N, R8E in the headwaters of Willame Creek.

Megascopic: Blue-gray dacite with sugary texture that has large quartz phenocrysts, salmon colored plagioclase phenocrysts and small specks of ferro-magnesian minerals.

Microscopic: Oligoclase (An 14) is about 43% of the rock, and occurs primarily as a matrix mineral along with fine-grained quartz crystals. The oligoclase is generally untwinned and shows much alteration to kaolin

PLATE XXXII

Specimen 48: Diorite. Fresh and altered plagioclase and augite grains. X 240, crossed nicols.

(5%). Some oligoclase has been altered to sericite. Primary quartz crystals comprise about 50% of the rock; 45% are in the matrix and 5% are phenocrysts. The quartz phenocrysts have rounded shapes, possibly from resorption, and are as much as 2 mm. in size. The grains are clear, and under crossed nicols have "saw tooth" borders (pl. XXXIII, p. 134). The "saw tooth" borders are secondary growths of quartz on the phenocrysts, and have the same crystal orientations. Biotite (about 0.1%) is mostly altered to pennine (2%), although some biotite grains are altered in part to muscovite(?) and magnetite. Magnetite is about 0.1% of the rock and occurs as a primary, very widely disseminated mineral.

<u>Specimen 50</u>: Dacite from NE$\frac{1}{4}$ projected sec. 9, T13N, R8E in the headwaters of Willame Creek about one mile southeast of specimen 49. The rock is very similar megascopically and microscopically to specimen 49 except that matrix feldspar and quartz grains are larger in size, and there is somewhat more biotite.

PLATE XXXIII

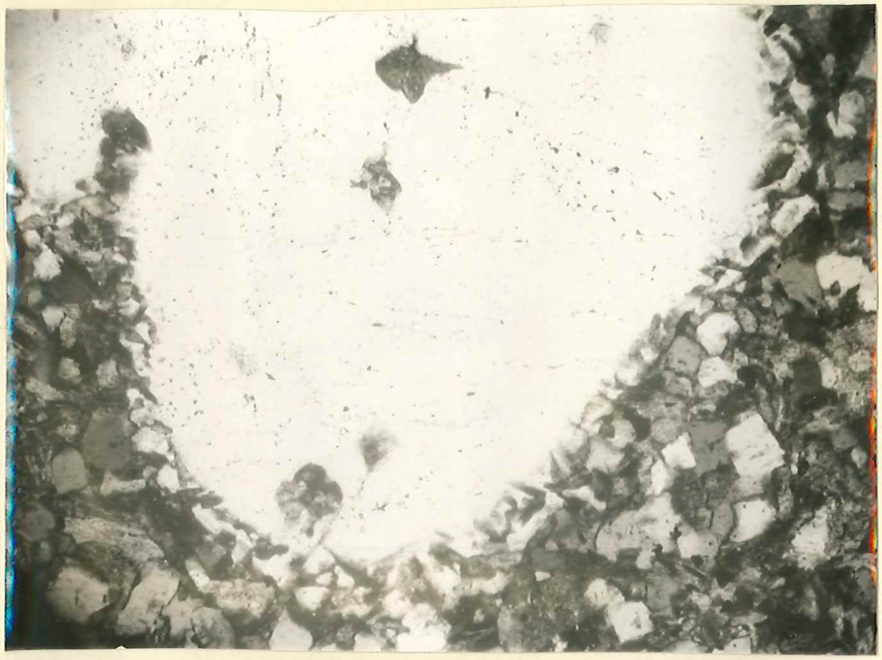


Figure 1. Specimen 49: Dacite. Quartz phenocryst with "sawtooth" border. Small quartz crystals rim the rounded quartz phenocryst and have the same optical orientation as the phenocryst. X 320, crossed nicols.

Figure 2. Same view as above. X 320, plain light.

S T R U C T U R A L   G E O L O G Y

GENERAL STATEMENT

The structural pattern of the area is one of broad, open, northwest trending folds that are oblique to the north-south trending Cascade Mountains. The pattern is dominated by two large anticlines near the eastern and western boundaries with an intervening, broadly folded structural low (pl. XXXVI, p. 154, and pl. XXXVII, section DD', p. 155). The crests of the two anticlines are a maximum of 20 miles apart. Broad folds occur within the volcanic Keechelus Group, and smaller folds occur within the sedimentary Puget Group. Faults are difficult to recognize, but are apparently of minor importance except for the northwest trending Catt Creek fault which extends through the central part of the area.

Minor crenulations can sometimes be plotted, but within the massive volcanic rocks attitudes are difficult to obtain. The importance of minor faults may be underestimated because of the lack of exposures. Mackin (1944, pp. 42-44) found several small faults in the underground workings southeast of Morton, which suggests that faults may be more important than is suspected from the surface exposures.

Dips throughout the area average about 25° to 35°, and are rarely over 50°. The maximum recorded dip is 85° which may be due to faulting.

TIME OF DEFORMATION

The angular unconformity between the Pliocene(?) Younger Volcanics and the lower Tertiary rocks of the mapped region indicates a post-Oligocene(?) period of folding. The time of this folding may be late

Oligocene or early Miocene, since to the east in the Mt. Aix quadrangle, Keechelus rocks dated as Oligocene unconformably underlie the Fifes Peak formation which is dated as lower Miocene (Warren, 1941, pp. 808-810; Abbott, 1953, pp. 82-83).

Weak folding periods may have occurred during the deposition of the Puget and Keechelus rocks, but the evidence is inconclusive. Disconformities may exist between Puget and Keechelus rocks in the Tilton River district, and between the middle and upper parts of the Keechelus Group.

The whole area was undoubtedly involved in the Cascade uplift, but the uplift is much to broad to be detected from the present limited area.

FOLDS

Skate Creek Anticline

The Skate Creek anticline was traced from the Nisqually River to south of the Cowlitz River, a distance of 16 miles. Its axial trace probably crosses the Nisqually River valley at an oblique angle and extends to north of the Nisqually River to a few miles west of Elbe, and may continue westward beneath the glacial deposits of Puget Sound. The northern extension of the fold is obscured by river valley deposits, by the unconformably overlying Younger Volcanics and by vegetation. The fold has not been mapped south of the Cowlitz River, but topographic trends indicate that it extends at least 15 miles south of the Cowlitz River, and probably farther. Its maximum length may be well over 30 miles.

The anticline plunges south, but no definite marker beds could be found for the exact calculation of the plunge. The crest of the fold mostly seems to be sharp, but it may be broad in places.

As shown in plate XXXIV (p. 138), the trend of the Skate Creek anticline in the Nisqually River district is approximately N75W, which is similar to fold trends developed across western Washington during the late Miocene epoch (Weaver, 1937, pp. 10-11). South of the Nisqually River, the axial trace makes a broad curve, turning gradually southward to a N20W trend. South of the Cowlitz River it may have a northeast trend.

Tilton River Anticline

The Tilton River anticline is not as well defined as the Skate Creek anticline, probably because it occurs in a section of relatively incompetent shales and sandstones of the Puget Group.

The anticline is of about the same magnitude as the Skate Creek anticline. Attitudes within the sedimentary rocks indicate that the anticlinal structure extends from two miles south of Mineral to the vicinity of West Fork, a distance of about seven miles. If the major fold follows South Fork as tentatively shown on plate XXXIV (p. 138), the maximum length within the mapped area is about 14 miles. It extends beyond the area to the south, and probably extends northward beneath the Younger Volcanics, and possibly converges with the Skate Creek anticline somewhere northwest of Elbe.

The Tilton River anticline apparently plunges southward. Its inferred northern extension trends about N15W, and may swing to a more westerly direction farther north. To the south, the axial trace makes a wide arc, changing in trend to about N30E. At West Fork the anticline may turn sharply to the southeast along the N50E trending South Fork. However, doubly plunging folds in the southern part of the Tilton River district (a culmination) may indicate that it continues to the southwest.

Of interest is the difference of structural trend between the northern and southern part of the Tilton River district. In the northern part of the district, the dominant trend is north-south to northeast-southwest. In the southern part of the district the dominant trend is about N50W. This change in trend coincides with the stratigraphic change discussed on page 39.

Silver Creek Depression

The region between the Tilton River and Skate Creek anticlines is a weakly folded structural low, part of which is a structural basin elongate in a northwest direction. The Silver Creek depression is bounded on the northeast by the Skate Creek anticline, and on the southwest and possibly south by an ill-defined south-plunging anticline. The northern extension of the depression is poorly defined, but it may continue northward as a broad synclinal downwarp between the Skate Creek and Tilton River anticlines. The rocks exposed in the downwarp are possibly the youngest Keechelus rocks within the area, and may be equivalent to the volcanic flows of the Skate Creek area.

Minor Folds

Nisqually River District

Sedimentary rocks of the Puget Group are less competent than the volcanic rocks of the Keechelus Group; consequently minor folds are more numerous within the Puget sandstones and shales of both the Nisqually and Tilton River districts. These folds are usually upright, open and gentle, with limbs that usually dip about 30° to 35°. Many of the folds are too small to be shown on the geologic map.

Two minor folds in the Copper Creek drainage basin trend N20W and plunge to the southeast. They die out southward toward the Skate Creek anticline.

Northward in the Puyallup River area, the Puget Group shales and sandstones have been thrown into numerous small anticlines and synclines (Gard, oral communication, 1955). These folds apparently die out rapidly southward, for none of them occur in the Ashord-Goat Creek section, except the two in the Copper Creek drainage basin.

Tilton River District

Numerous minor folds occur in the Tilton River district, but they are incompletely mapped.

In the northern part of the Tilton River district, minor crenulations trend north-south, parallel to the dominating Tilton River anticline. South of West Fork the folds trend about N50W, and are doubly plunging.

FAULTS

The faults of the area trend northeast and northwest, generally at an oblique angle to the major folds. As far as is known, they are all normal faults, but since only two possible fault exposures were seen, the relative directions and amounts of movement along the faults can only be estimated. Faults may be much more prevelant than are shown on the geologic map.

Catt Creek Fault

The largest known fault trends about N30W through the central part of the mapped area. Its throw is estimated to be about 5000 feet, and it is probably a normal fault. The northeast side of the fault appears to have moved northwest relative to the southwest side. In E½ sec. 24, T14N, R6E, a fault exposed in a road cut dips 55° southwest, and may be an exposure of the Catt Creek fault (fig. 3, p. 141).

Figure 3. Exposure of Catt Creek fault. Note downward drag of bedded tuffs on footwall of fault, indicating direction of relative movement. View is north.

Evidence for the Catt Creek fault is the sharp bend in structural trends across Catt Creek, and an apparent change in the stratigraphy across the Catt Creek valley.

Minor Faults

Small faults may occur in several places within the area, but there is little factual basis for drawing them on the geologic map.

In sec. 23, T15N, R6E is a probable fault which strikes about N40E. It may be equivalent to a fault that has cut Puget sandstones along North Fork Mineral Creek, but the correlation is uncertain. It is not known whether the fault is normal or reverse, but it probably dips at a high angle and may be vertical. The northwest side has apparently moved down relative to the southeast side.

In the Tilton River district, a fault which may cut the diorite sill in T14N, R5E trends about N50E. The northwest side has moved up relative to the southeast side. Its dip is unknown.

In T12N, R5E, two faults occur near the nose of a south-plunging anticline. One of the faults is a normal fault and trends N75W, and dips 80° to the northeast. The other fault, trending N50E, may also be a normal fault; the northwest side up relative to the southeast side. The area between the two faults is a graben.

tures in a 3000 foot gorge. Since the Cowlitz River is believed to be an old topographic feature (Coombs, 1936, p. 197) and Silver Creek is nearly graded to the Cowlitz River, Silver Creek may have originated along with the Cowlitz.

Several of the large streams and tributaries follow structural trends, and are believed to be subsequent in origin. Among these are Skate Creek, Willame Creek, Berry Creek, Copper Creek, Catt Creek, and the tributaries to Mineral Creek, North Fork Mineral Creek, Silver Creek, and the Tilton River. As far as is known, Catt Creek is the only fault-controlled stream. Copper Creek and its tributaries flow on synclinally folded sedimentary rocks. The close relation between Copper Creek and the syncline is believed to be accidental rather than due to recent folding.

An interesting feature is the pattern of the Nisqually-Cowlitz River drainage divide (pl. XXXV, p. 144), which in part reflects the major structural pattern of the region. On the east side of the area, the divide bends southward in the vicinity of the south-plunging Skate Creek anticline. Farther west the divide bends northward near the Silver Creek synclinal depression, and still farther west it again bends southward, presumably in the vicinity of another south-plunging anticline.

GLACIATION

Introduction

The streams of the area are U-shaped in transverse profile, and head in cirque lakes (tarns), dissected cirques, and greatly dissected cirque-like basins. Glacial deposits are found in the valleys through-

P H Y S I O G R A P H Y

GENERAL STATEMENT

The streams of the area drain into the westward flowing Nisqually and Cowlitz Rivers, both of which occupy relatively wide glaciated valleys. The drainage pattern is largely controlled by the gently tilted, alternating hard and soft clastic-volcanic rocks and volcanic flows, although most of the larger streams are not affected by rock hardness.

The region was glaciated by valley glaciers at least twice during the Wisconsin(?) glacial period. Glacial and Recent river deposits are not differentiated, but their possible extent is indicated on the glacial map (pl. XXXIX, p. 157).

STREAMS

The streams in the Elbe-Packwood area are consequent(?) and subsequent in origin, and have resequent and probably insequent tributaries. The drainage pattern is a combination of dendritic and trellis, although annular patterns can be seen (pl. XXXV, p. 144).

Mineral Creek, North Fork Mineral Creek, Silver Creek and the Nisqually River, the four larger streams of the mapped area cross structural trends, and possibly are consequent on an earlier erosion surface. The Nisqually River is pre-Mount Rainier in age (Coombs, 1936, p. 197), and Mineral Creek and North Fork Mineral Creek, which are tributary to the Nisqually River may have originated at the same time. Coombs (1936, p. 198) suggests that drainage prior to the building of Mount Rainier was consequent on the west slope of the Cascades, which, in this area is across structural trends. Silver Creek, which flows into the Cowlitz River, crosses east-west trending strucout the area. There is no evidence of continental glaciation in any part of the mapped area.

The time of valley glaciation is not known, but a difference in levels of the higher, relatively fresh lake-bearing cirques, and the older and lower, well dissected cirque-like basins indicates at least two distinct periods. The more recent cirques occur between 4500 and 3600 feet in elevation, and generally are on north-facing slopes. Bertha May Lakes, Granite Lake and Lake Tannamus, the largest cirque-lakes of the area, are closest to Mount Rainier. These higher level cirques may be latest Wisconsin in age.

In general, the larger streams of the area, such as Mineral Creek, North Fork Mineral Creek, Catt Creek and Skate Creek, head in dissected cirques which lie between the 2500 foot and the 3500 foot contour lines. The recognition of the older cirques is difficult however, for erosion has nearly erased their original forms. Concurrently with the erosion of the cirques, the larger streams mentioned above have cut 100 to 200 feet below their glaciated floors, and now flow in V-shaped gorges; best displayed in Catt Creek valley (fig. 4, p. 146). The downcutting of these streams is believed to be due to a post-glacial regrading of the Nisqually and Cowlitz River valleys, possibly due ultimately to sea level changes, rather than due to recent regional uplift of the area.

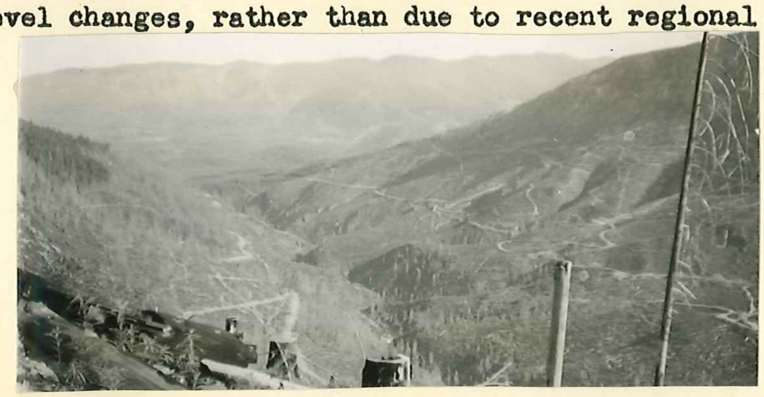


Figure 4. U-shaped valley with inner gorge incised 100 to 200 feet below former valley floor. View looking northward toward Nisqually River valley.

Skate Creek Valley

The topographic map pattern, together with outcrops of unweathered glacial deposits strongly indicate that a Wisconsin(?) glacier which headed in the upper part of the Nisqually River once flowed through Skate Creek valley to the Cowlitz River. Large boulders and cobbles found in till deposits near Johnson Creek are identical to rocks of the Snoqualmie Granodiorite which crop out in Mount Rainier National Park along the Nisqually River (Coombs, 1936, geologic map); virtual proof that the glacier came from the park. Also, near Johnson Creek, glacio-fluvial sands and gravels dip southward at approximately the same angle as the gradient of Skate Creek.

Prior to this late episode of glaciation, the Nisqually River may have flowed through Skate Creek, but deposition of morainal material may have diverted the now existing upper Nisqually River westward into a valley cut by the drainage from Tahoma and Kautz Creeks which flow from Mount Rainier. This diversion is suggested by (1) the sharp bend from south to west of the Nisqually River in NW$\frac{1}{4}$ sec. 5, T15N, R8E, (2) the change from a southwest to west direction of Horse Creek where it enters the valley of Skate Creek, and (3) the low, flat, swampy drainage divide between the Nisqually River and Skate Creek, which suggests deposition of morainal material at the head of the now existing Skate Creek by the glacier during its retreat.

Skate Creek is apparently not graded to the Cowlitz River (fig. 5, p. 148), but if the downcutting of Skate Creek continues, the upper Nisqually River is likely to become captured by the headward erosion of Skate Creek.

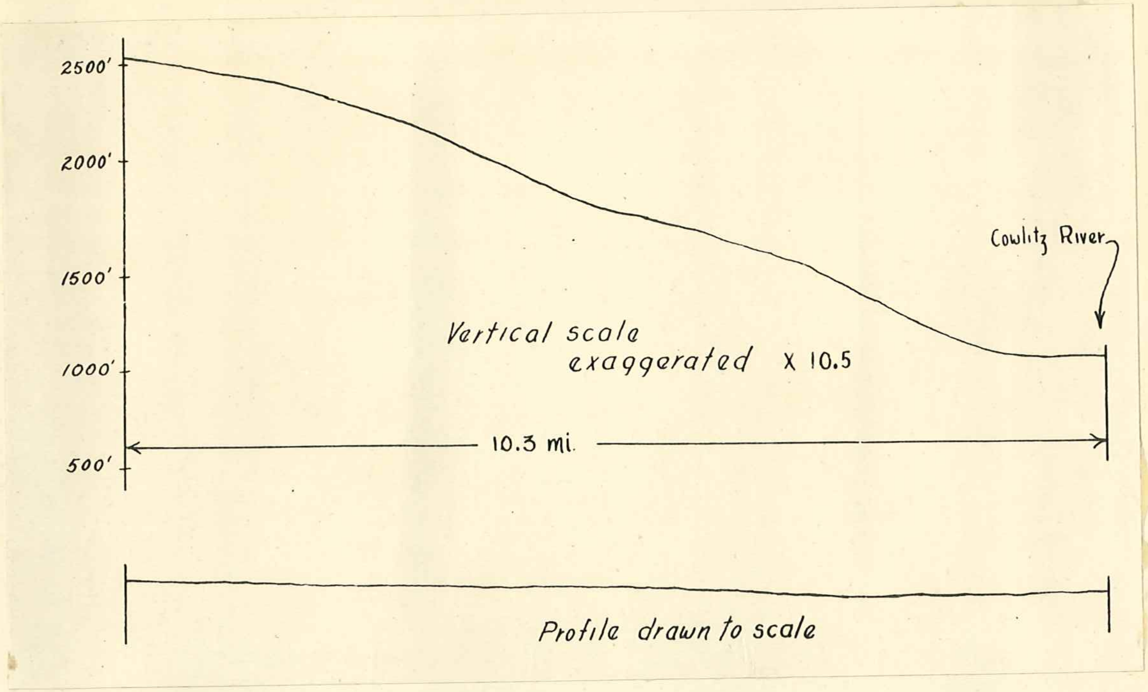


Figure 5. Longitudinal profile of Skate Creek. Exaggerated drawing indicates that the stream is not graded.

Silver Creek Drainage Basin

Glacial deposits found throughout the Silver Creek drainage basin give evidence of at least two periods of valley glaciation. Several road cuts reveal a probably partial stratigraphic record of events.

The lowest recognized stratigraphic glacial unit in the Silver Creek drainage system is unstratified, unsorted till which contains large and angular, fresh andesite blocks as much as 10 feet across. The thickness of the till is unknown. Lying above the till in the Silver Creek valley are well bedded silts, sands and gravels of unknown thickness. Martin Creek, which is tributary to Silver Creek, contains blue clay lake deposits which lie above a till deposit. The clay may be equivalent in age to the silts and gravels which also lie above till in Silver Creek valley. Lying unconformably above the clays in Martin Creek, and above the well bedded gravels and sands in Silver

Creek, is poorly sorted, unstratified material thought to be till. Above this till(?) are crudely bedded, fine-grained silts containing a few interspersed cobbles and pebbles. Two separate ice advances are indicated by the separate till layers. The volcanic particles within the till layers are not weathered, which indicates that they were probably deposited at a late glacial stage.

Nisqually River Valley

The glacial history of the Nisqually River and its tributaries has been influenced by at least two periods of continental glaciation which blocked the Nisqually River valley a few miles west of the area. The earlier period of glaciation (Iowan?) probably blocked the valley about five miles west of Elbe. The later period (Wisconsin?) blocked the Nisqually valley near La Grande.

The last major ice advance in the Nisqually River valley (late Wisconsin?) apparently did not advance far beyond the town of National. Unweathered glacial deposits (till?) occur in NE$\frac{1}{4}$ sec. 28, T15N, R6E in a road cut along State Highway 5 west of Ashford, and in SE$\frac{1}{4}$ sec. 4, T14N, R6E, 400 feet above the general elevation of the present valley floor. No unweathered glacial deposits were observed farther west.

Mineral Creek and North Fork Mineral Creek

Both of these streams head in the same drainage basin, the divide separating the two being about 25 feet in height. North Fork heads in the North Fork Swamp, while Mineral Creek heads slightly south of the swamp. The basin for these two streams appears to be a dissected cirque that existed possibly between about 3200 feet and 2800 feet in elevation. The former glacier presumably sent ice tongues down both valleys. Both streams are now actively downcutting into Keechelus volcanic rocks which trend nearly perpendicular to the streams. Fresh and well-weathered glacial deposits occur in the vicinity of North Fork Swamp, indicating that this area may have been glaciated more than once.

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Nr.	Page Descr.	Photo-micrograph	Rock Description and locality
SECOND PUGET TONGUE:			
11	29		Impure sandstone. Near upper contact of group.
12	31		Impure sandstone, muscovite bearing. Upper part.
13	31		Arkose. Middle of tongue.
SECOND KEECHELUS TONGUE			
14	32		Volcanic pebble conglomerate. Near lower contact.
15	33		Tuffaceous sandstone.
THIRD PUGET TONGUE			
16	34		Fossiliferous sandstone.
*LEWIS COUNTY:			
17	36	38	Arkose.
18	37		Arkose. Osborne Mountain.
Tilton River District			PUGET GROUP
19	44		Volcanic graywacke. Tongue of Lower Keechelus (?).
20	44		Impure arkose. Near East Creek.
21	45	46	Arkose. Near upper contact.
22	45		Arkose. Just north of South Fork.
23	47		Arkose. $1\frac{1}{2}$ mi. N. of Morton.
24	47		Shale. 1 mi. N. of Morton.
25	48	49	Pebbly arkose. 3 mi. S. E. Morton.
EXTRUSIVE IGNEOUS ROCKS			
26	50		Andesite. Just north of South Fork.
27	50		Andesite.
28	50		Andesite.
29	51		Andesite. 3 mi. N. W. Morton.
INTRUSIVE IGNEOUS ROCKS INTO PUGET GROUP-			Tilton River District.
30	127	128	Hypersthene gabbro. Near East Creek.
31	129		Hypersthene diorite. Base of a sill. Summit Creek.

LOT 6 (Petrographic)

FISHER, RICHARD VIRGIL

PhD 1957 Univ. of Wash. Thesis nr. 82

Stratigraphy of the Puget Group and Keechelus Group in the Elbe-Packwood

Region of Southwestern Washington.

Location: Pierce and Lewis Counties.

Listed below are the hand specimens and thin sections contained in the collection which is stored in Room 4, Johnson Hall, Tray nr.

Distr. of copies:
Log of the Petrographic Museum, Univ. of Wash.
With the thesis, nr. 82, room 42.
With the collection, room 4.

Hand specimens and corresponding thin sections are numbered serially from 1 thru 64.
Note: Hand specimens 34, 35 and 62 are missing. No description or specimens of 62.
All thin sections are present, except 62.

Nr.	Page Descr.	Photo-micrograph	Rock Description and Locality
PIERCE COUNTY:			
"OLDER VOLCANICS" - Eocene (?)			
1	11		Porphyritic Andesite
2	12	13	Tuff-Agglomerate
LOWER PUGET TONGUE:			
3	22		Sandstone. ½ mi. N. W. Ashford.
4	22	23	Sandstone. ½ mi. N. E. Ashford. Near upper contact.
INTRUSIVE IGNEOUS ROCKS INTO PUGET GROUP: Nisqually River District			
5	123		Basalt. In a sill (?). 1 mi. N. Ashford.
6	124		Andesite (?). In a sill (?), upper. 1 mi. N. Ashford.
7	124		Andesite. In a dike. 1½ mi. N. W. Ashford.
LOWER KEECHELUS TONGUE			
8	26	27	Graywacke. Matrix of clastic volcanic breccia.
9	26		Andesite cobble from clastic breccia.
10	28		Volcanic graywacke. Near lower contact.

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
32	129		Diorite. Top of the sill, Summit Creek.
33	130		Hypersthene diorite.

MIDDLE KEECHELUS GROUP- MEMBER "A"- LAHARIC VOLCANIC BRECCIAS

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
*34	77		Volcanic breccia, laharic origin. Johnson-Skate Cr. Junction.
*35	79		Andesite pebble. From pebble sandstone underlying a breccia.
36	80	82	Volcanic breccia, laharic origin. 1 mi. W. of Randle.

MEMBER "A"- PYROCLASTIC VOLCANIC BRECCIAS

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
37	83	85	Pyroclastic breccia. Mineral Creek Valley.
38	84		Pyroclastic breccia. Near west entrance, Rainier Nat. Park.
39	86		Pyroclastic breccia. Along Teeley Creek.
40	87		Siliceous (?) graywacke. Skate Cr. Road.

UPPER KEECHELUS GROUP

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
41	105	107	Tuff. Near Catt Creek.

MIDDLE KEECHELUS GROUP- MEMBER "A"- FLOW ROCKS

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
42	92		Quartz bearing andesite. South slope Skate Mountain.
43	93	94	Augite andesite. Willame Creek.
44	95		Andesite.
45	95		Pyroxene andesite.
46	95	97	Augite basalt. 1 mi. W. of Tannamus Lk.
47	96		Dacite (?). Along Willame Creek.

INTRUSIVE ROCKS IN THE KEECHELUS GROUP

Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
48	130	132	Diorite. ½ mi. N. W. Lk. Tannamus.
49	131	134	Dacite. Headwaters of Willame Creek.
50	133		Dacite. Headwaters of Willame Creek.

MIDDLE KEECHELUS GROUP- MEMBER "A"- VOLCANIC GRAYWACKE

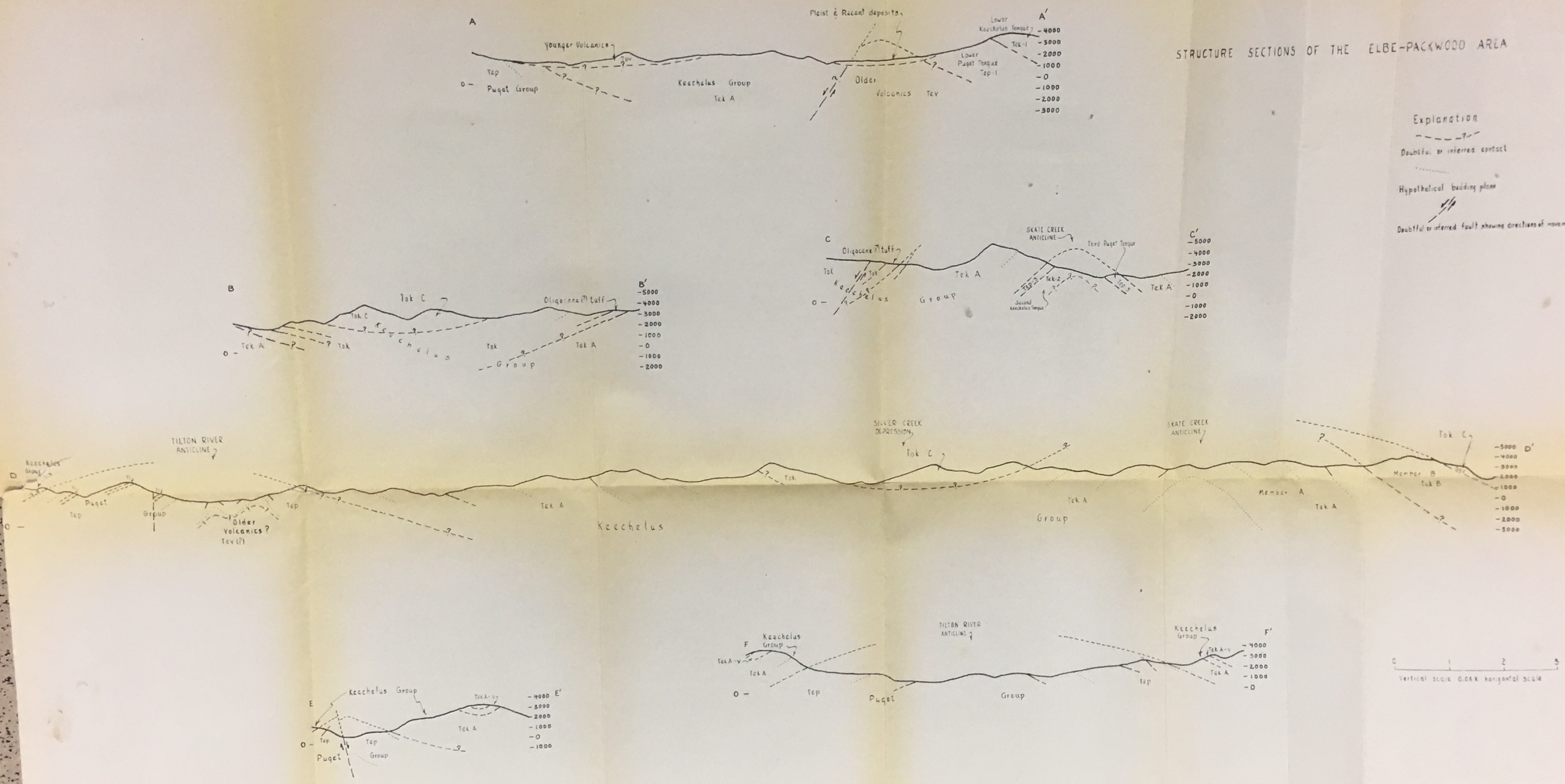
Nr.	Page Descr.	Photo-micrograph	Rock description and Locality
51	88	89	Volcanic graywacke. Willame Cr, ½ mi. N. E. of Long Lake.
52	88		Volcanic graywacke. Willame Cr.

*Hand specimen is missing.

Nr.	Page Descr.	Photo-micrograph	Rock Description and Locality
UPPER KEECHELUS GROUP			
53	106	109	Andesite. Near junction of Johnson and Skate Creeks.
54	108		Andesite. Same as above.
MIDDLE KEECHELUS GROUP- MEMBER "B"			
55	101		Volcanic graywacke.
56	101		Volcanic graywacke. Along a tributary of Willame Creek.
57	102		Fine grained volcanic graywacke. Near Skate Creek.
58	103	104	Volcanic Graywacke. Near 57.
"YOUNGER VOLCANICS"			
59	117		Hypersthene basalt. 2 mi. S. E. of National.
60	117		Hypersthene basalt. Same as above.
61	121		Hypersthene basalt.
62	(not described; both hand specimen and thin section missing)		
63	118	119	Hypersthene basalt. Sach's Corner at Elbe.
64	118	120	Trachyte. $2\frac{1}{2}$ mi. E. of Mineral.

PLATE XXXVII

STRUCTURE SECTIONS OF THE ELBE-PACKWOOD AREA



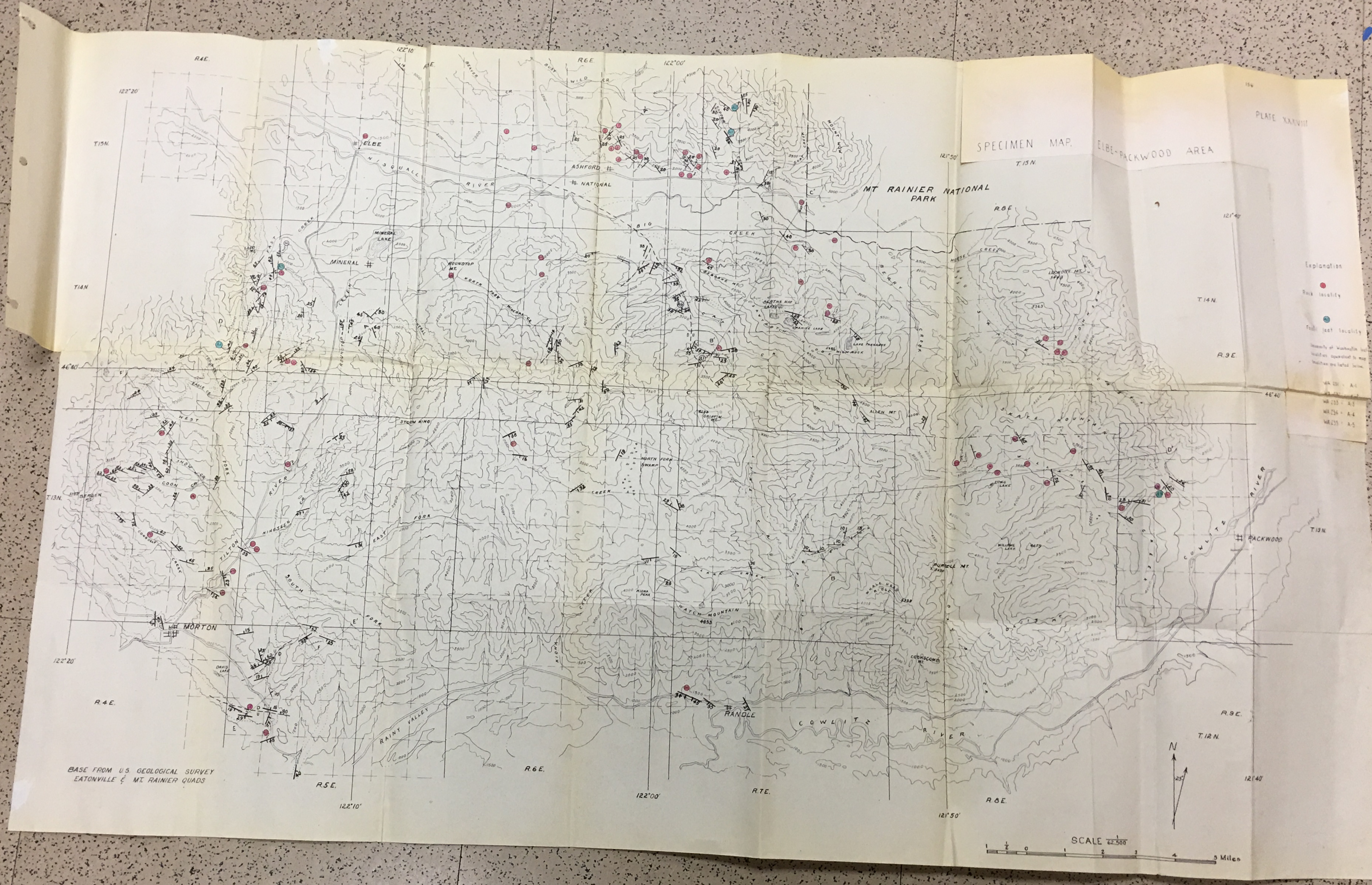

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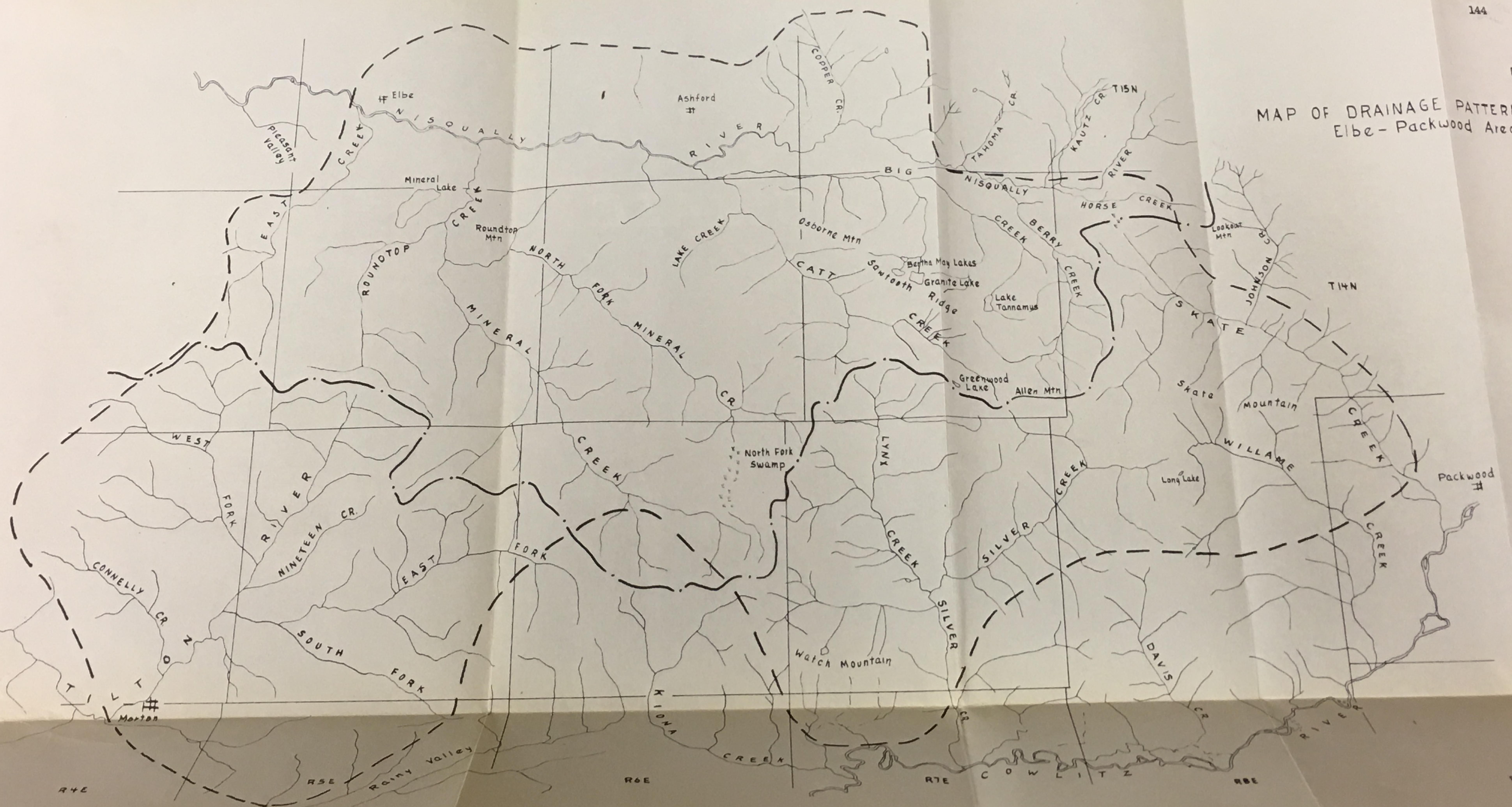
PLATE XXXVIII
SPECIMEN MAP, ELBE-PACKWOOD AREA
Explanation
Rock locality
Fossil leaf locality
WA 231 = A-1
WA 233 = A-3
WA 234 = A-4
WA 235 = A-5
MT RAINIER NATIONAL PARK
ELBE
ASHFORD
NATIONAL
MINERAL
MINERAL LAKE
MORTON
RANDLE
PACKWOOD
COWLITZ RIVER
NISQUALLY RIVER
BIG CREEK
TILTON RIVER
RAINY VALLEY
LOOKOUT MT.
WATCH MOUNTAIN
BUMPING MT
COCKSCOMB MT.
ALLEN MT
NORTH FORK SWAMP
R.4E.
R.5E.
R.6E.
R.7E.
R.8E.
R.9E.
T.15N.
T.14N.
T.13N.
T.12N.
122°20'
122°10'
122°00'
121°50'
121°40'
46°40'
BASE FROM U.S. GEOLOGICAL SURVEY
EATONVILLE & MT. RAINIER QUADS
N
SCALE 1/62,500
5 Miles


PLATE XXXIX
QUATERNARY DEPOSITS, ELBE - PACKWOOD AREA
Explanation
Recent & Pleistocene
Unconsolidated glacial and stream deposits
Inferred boundaries
MT RAINIER NATIONAL PARK
ELBE
ASHFORD
NATIONAL
NISQUALLY RIVER
BIG CREEK
MINERAL LAKE
Mineral
MORTON
RANDLE
PACKWOOD
COWLITZ RIVER
RAINY VALLEY
R.4E.
R.5E.
R.6E.
R.7E.
R.8E.
R.9E.
T.15N.
T.14N.
T.13N.
T.12N.
122°20'
122°10'
122°00'
121°50'
121°40'
46°40'
BASE FROM U.S. GEOLOGICAL SURVEY
EATONVILLE & MT. RAINIER QUADS
SCALE
Miles
N

PLATE XXXVI
GEOLOGICAL MAP, ELBE-PACKWOOD AREA
Explanation
Recent & Pleistocene
Not represented on this map
Late Pliocene (?)
Tpv
YOUNGER VOLCANICS
ANGULAR UNCONFORMITY
Oligocene (?)
Tek C
Andesite flows
DISCONFORMITY (?)
Tek B
Member B
KEECHELUS GROUP
Upper Eocene
Tek A
Member A
PUGET GROUP
LOWER KEECHELUS GROUP
Middle (?) Eocene
Tev
OLDER VOLCANICS
Symbols
Contact; known, doubtful, inferred
Attitude of beds
Doubtful attitude
Attitude of fault
Attitude from published reports
Rock locality
Fossil leaf locality
MT RAINIER NATIONAL PARK
ELBE
ASHFORD
MINERAL
MORTON
RANDLE
PACKWOOD
COWLITZ RIVER
SCALE
Miles
BASE FROM U.S. GEOLOGICAL SURVEY
EATONVILLE & MT. RAINIER QUADS

PLATE XXXV

MAP OF DRAINAGE PATTERN
Elbe - Packwood Area



Explanation

Approximate boundary of mapped area

Cowlitz-Nisqually divide

Scale 1/125,000

N

Base from U.S.G.S. Eaton
and Mt Rainier quadr

COLUMNAR SECTION OF PARTS OF MEMBERS A & B, WILLAME CREEK AREA

X= Specimen localities

Scale 1" = 1000'

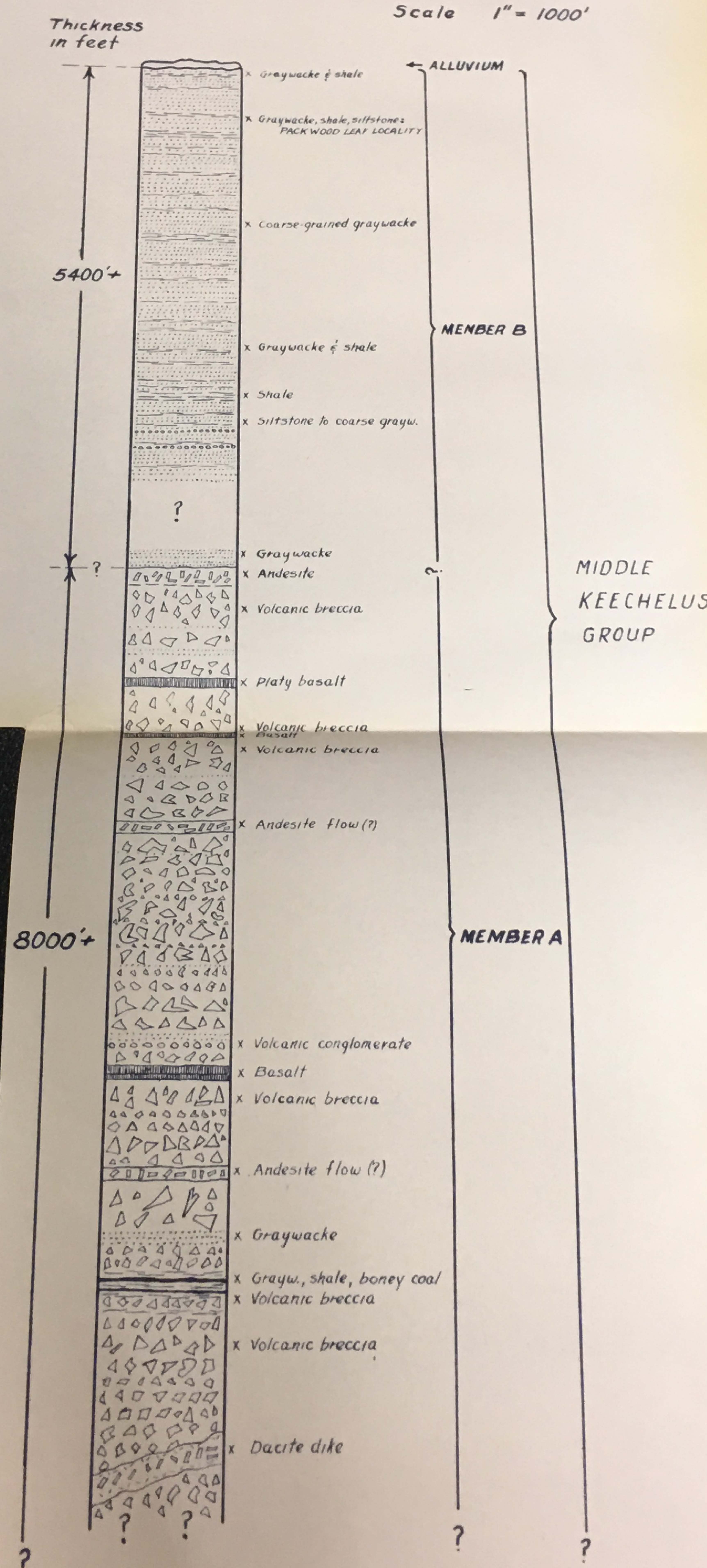



PLATE XXXIV
STRUCTURE MAP
Elbe-Packwood Area
Legend
Fault, showing dip (dashed where doubtful or inferred, question mark where questionable)
U, upthrown side; D, downthrown side
Anticline, showing plunge (dashed where doubtful or inferred, question mark where questionable)
Syncline, showing plunge
Scale 1/125,000
N
Base from U.S.G.S. Eatonville and Mt Rainier quadrangles
Elbe
Ashford
Packwood
Morton
NISQUALLY RIVER
NORTH FORK MINERAL CREEK
MINERAL CREEK
CATT CREEK FAULT
SKATE CREEK ANTICLINE
SKATE CREEK
SILVER CREEK DEPRESSION
SILVER CREEK
WILLAME CREEK
TILTON RIVER ANTICLINE
TILTON RIVER
COWLITZ RIVER
T15N
T14N
T13N
T12N
R4E
R5E
R6E
R7E
R8E
R9E
55°
80°

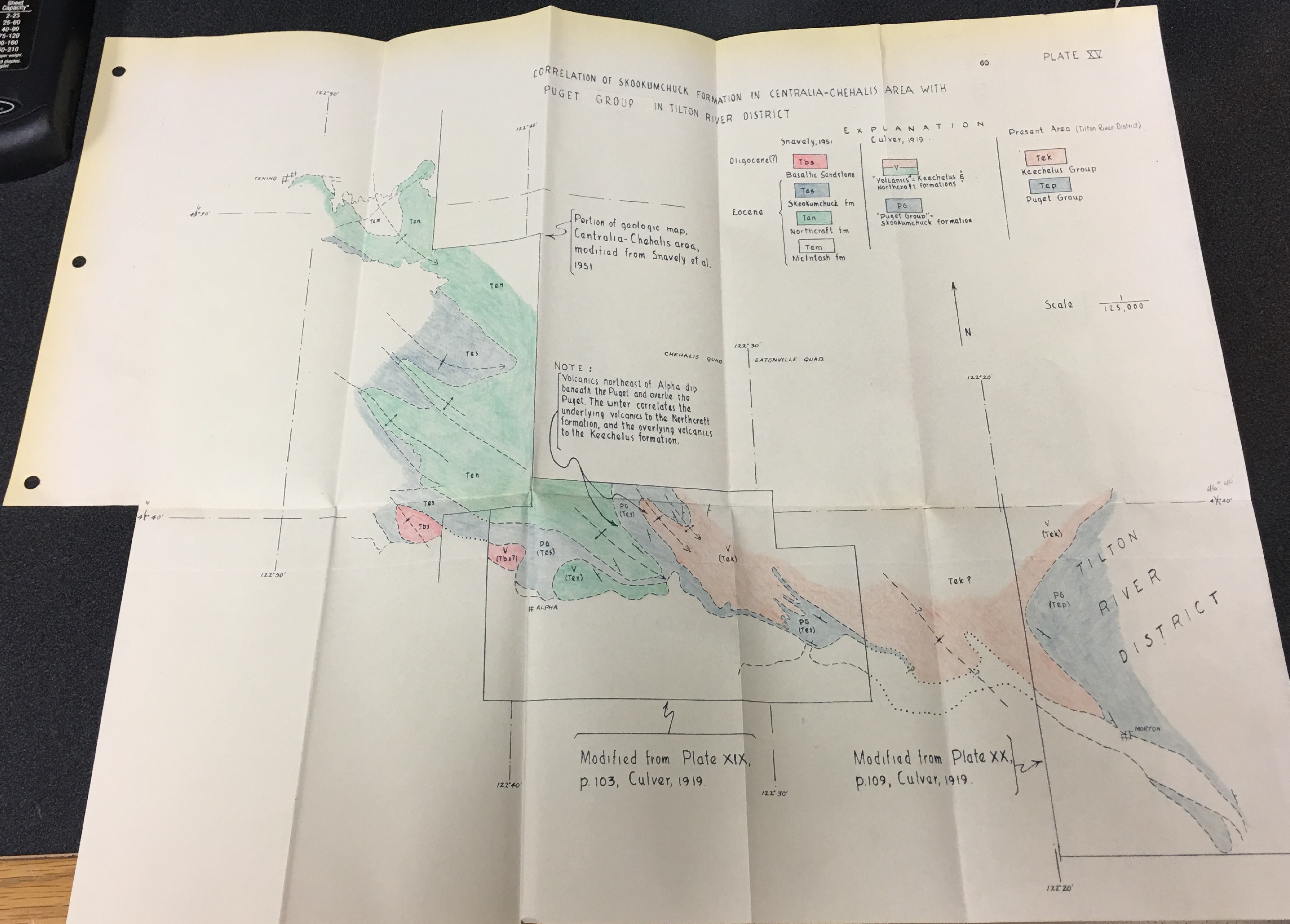

CORRELATION OF SKOOKUMCHUCK FORMATION IN CENTRALIA-CHEHALIS AREA WITH
PUGET GROUP IN TILTON RIVER DISTRICT
EXPLANATION
Snavely, 1951
Oligocene(?)
Tbs
Basaltic Sandstone
Eocene
Tes
Skookumchuck fm
Ten
Northcraft fm
Tam
McIntosh fm
Culver, 1919.
V
"Volcanics" = Keechelus & Northcraft formations
PG
"Puget Group" = Skookumchuck formation
Present Area (Tilton River District)
Tek
Keechelus Group
Tep
Puget Group
N
Scale 1/125,000
Portion of geologic map, Centralia-Chehalis area, modified from Snavely et al. 1951
NOTE:
Volcanics northeast of Alpha dip beneath the Puget and overlie the Puget. The writer correlates the underlying volcanics to the Northcraft formation, and the overlying volcanics to the Keechelus formation.
CHEHALIS QUAD
EATONVILLE QUAD
TENINO
ALPHA
MORTON
TILTON RIVER DISTRICT
Tek ?
Modified from Plate XIX, p. 103, Culver, 1919.
Modified from Plate XX, p. 109, Culver, 1919.
122°50'
122°40'
122°30'
122°20'
46°50'
46°40'

PLATE V

GEOLOGIC MAP, ASHFORD-GOAT CREEK SECTION

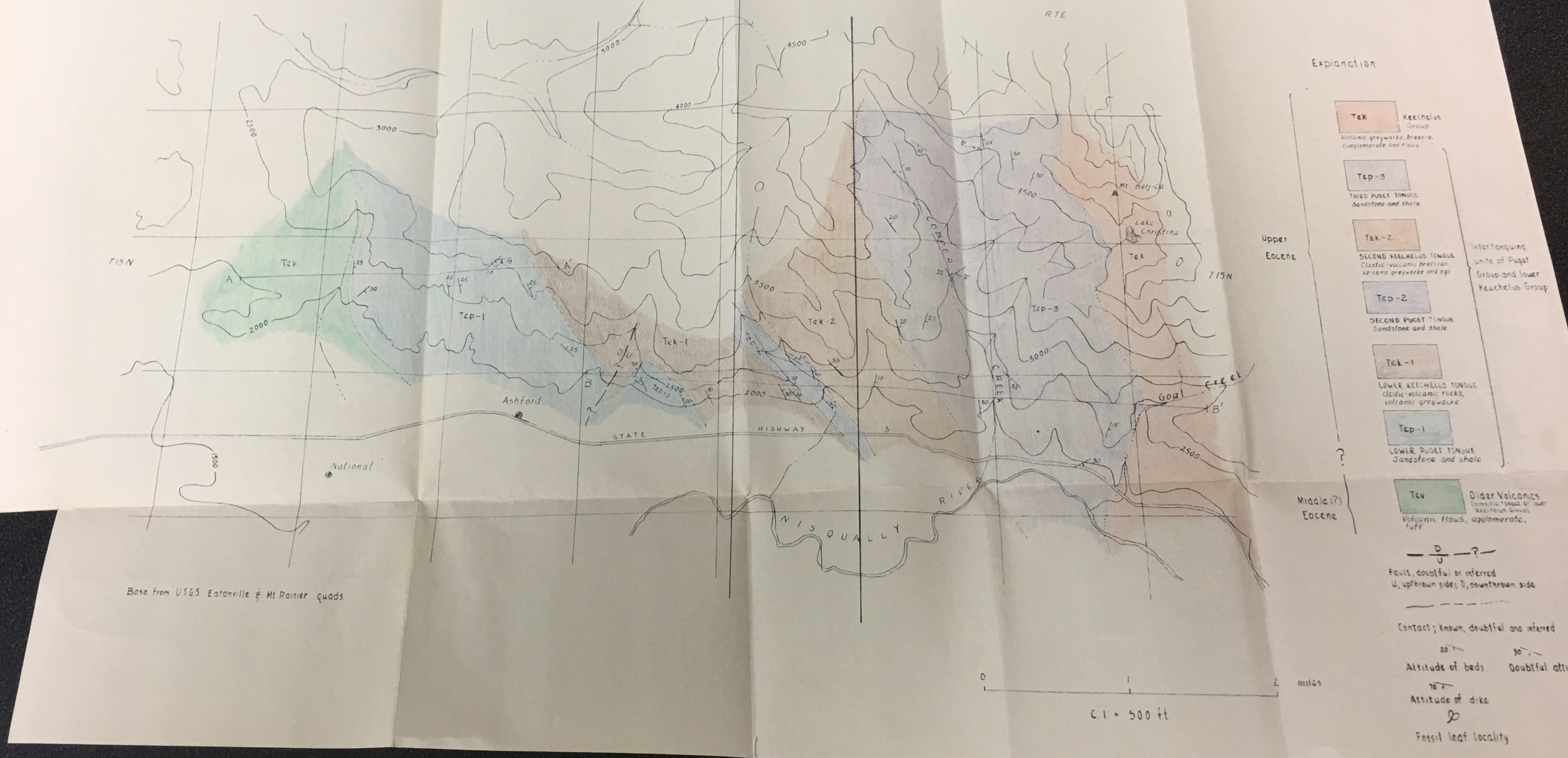


PLATE VI

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Ashford-Goat Creek Structure & Columnar Sections