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STRUCTURE AND STRATIGRAPHY OF THE KEECHELUS VOLCANIC GROUP AND ASSOCIATED TERTIARY ROCKS IN THE WEST–CENTRAL CASCADE RANGE, WASHINGTON.

University of Washington, Ph.D., 1963
Geology

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STRUCTURE AND STRATIGRAPHY OF THE KEECHELUS VOLCANIC GROUP AND ASSOCIATED TERTIARY ROCKS IN THE WEST-CENTRAL CASCADE RANGE, WASHINGTON

by

PAUL ELLSWORTH HAMMOND

A thesis submitted in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

UNIVERSITY OF WASHINGTON

1963

Approved by Howard A Coombs

Department Geology

Date May 28, 1963

UNIVERSITY OF WASHINGTON

Date: May 13, 1963

We have carefully read the thesis entitled "Stratigraphy and Structure of the Keechelus Volcanic Group and Associated Tertiary Rocks in the West-Central Cascade Range, Washington" submitted by Paul E. Hammond in partial fulfillment of the requirements of the degree of Doctor of Philosophy *and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the thesis.*

The central Cascades of Washington has been an area of geological controversy since the excellent pioneer work of Smith and Calkins in 1903-1906. The great accumulations of sediments, volcanic debris and lava flows are difficult to trace, with any degree of assurance, in this rugged and heavily forested area. This thesis on the stratigraphy and structure of the Keechelus Volcanic Group is particularly significant because the writer, through many years of experience with these lithologic units, was able to discover unique tuffs that were recognizable over great horizontal distances. These tuffs provided the basic information needed to establish a definite sequence for the interstratified sedimentary and volcanic rocks and their correlation throughout the map area. In addition, the tuff units were invaluable in working out the structural complexities in this portion of the Cascade Range.

This thesis contains (1) descriptions of the various rock types, both field and petrographic, (2) measured stratigraphic sections, (3) conditions of deposition of the various rock units (4) a map and description of the salient structural features and (5) a resume of the geologic history of the area. For the first time we have a series of described stratigraphic sections arranged in a sequence that extends from middle late Eocene time to the Quaternary.

Standards of reference for future geologic research in the central Cascades have been established by the delineation of type sections for each stratigraphic unit. Lack of such typology has seriously impeded the investigations of previous workers. Though geologic work in the Cascades may still be regarded as reconnaissance, yet the care in describing and correlating the lithologic units in this difficult map area is so thorough that the information presented in this thesis will, for many years to come, serve as the definitive work on the central Cascades of Washington.

THESIS READING COMMITTEE: Howard A. Coombs

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Bates McKee

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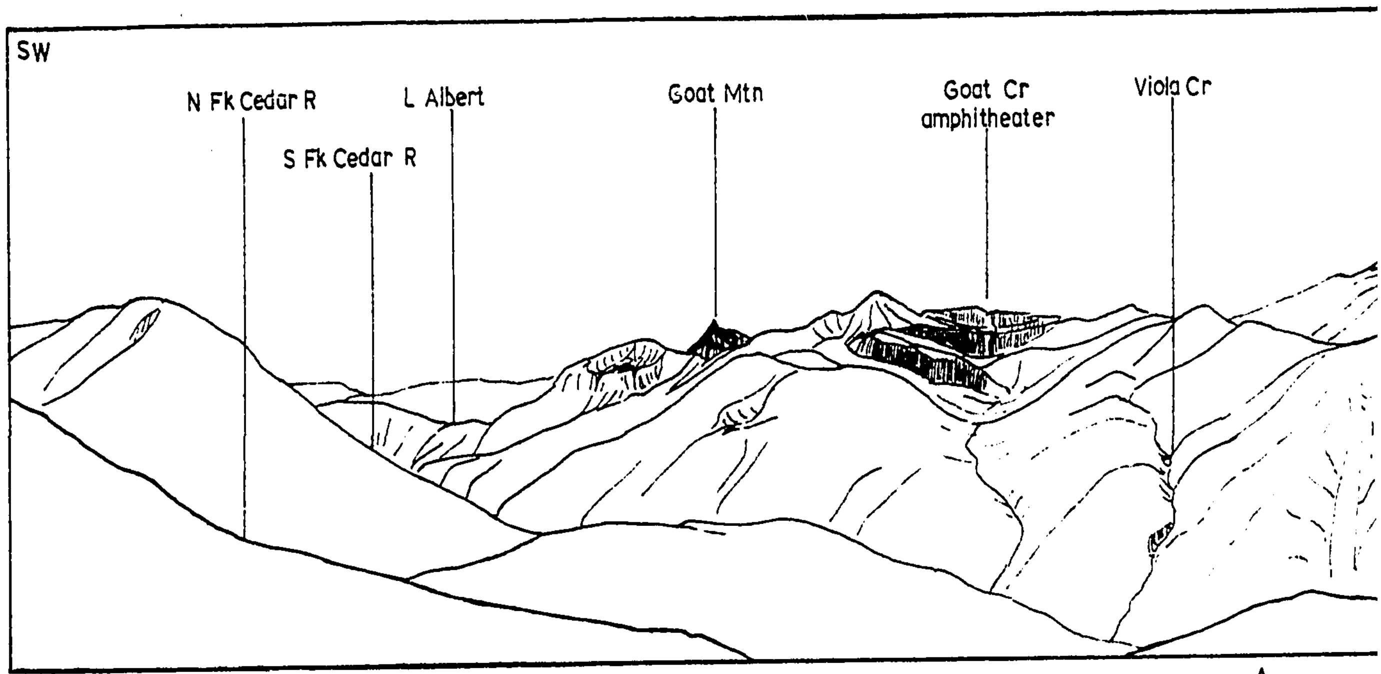
Date *May 29, 1963*

PLATE 3

Panoramic Views

A. Upper Cedar River valley from near Bear Creek in NE$\frac{1}{4}$, sec. 3, T. 21 N., R. 10 E., looking southwest to west. Showing valley of South Fork of Cedar River, Goat Mountain, Goat Creek amphitheater, outcrops of Cougar Mountain Formation, Seattle Creek valley, outcrops of hornfels zone of Snoqualmie granodiorite near Findley Lake. Looking westward down Cedar River valley, Chester Morse Lake and Little Mountain are in distance.

B. Green River valley from Huckleberry Mountain. Looking northwest to northeast. Showing Cougar Mountain, Rooster Comb, McCain Creek valley, Goat Mountain, Meadow Mountain, Sunday Creek valley, Stampede Pass, and Kelly Butte.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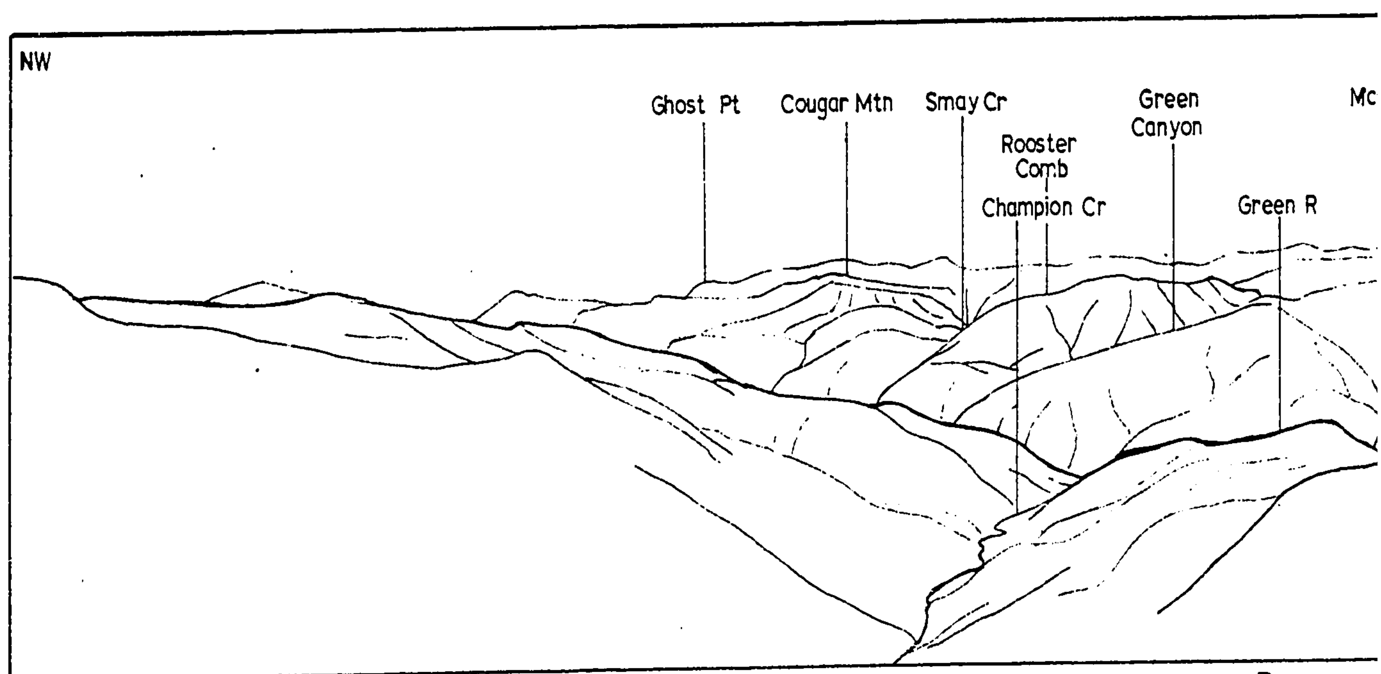
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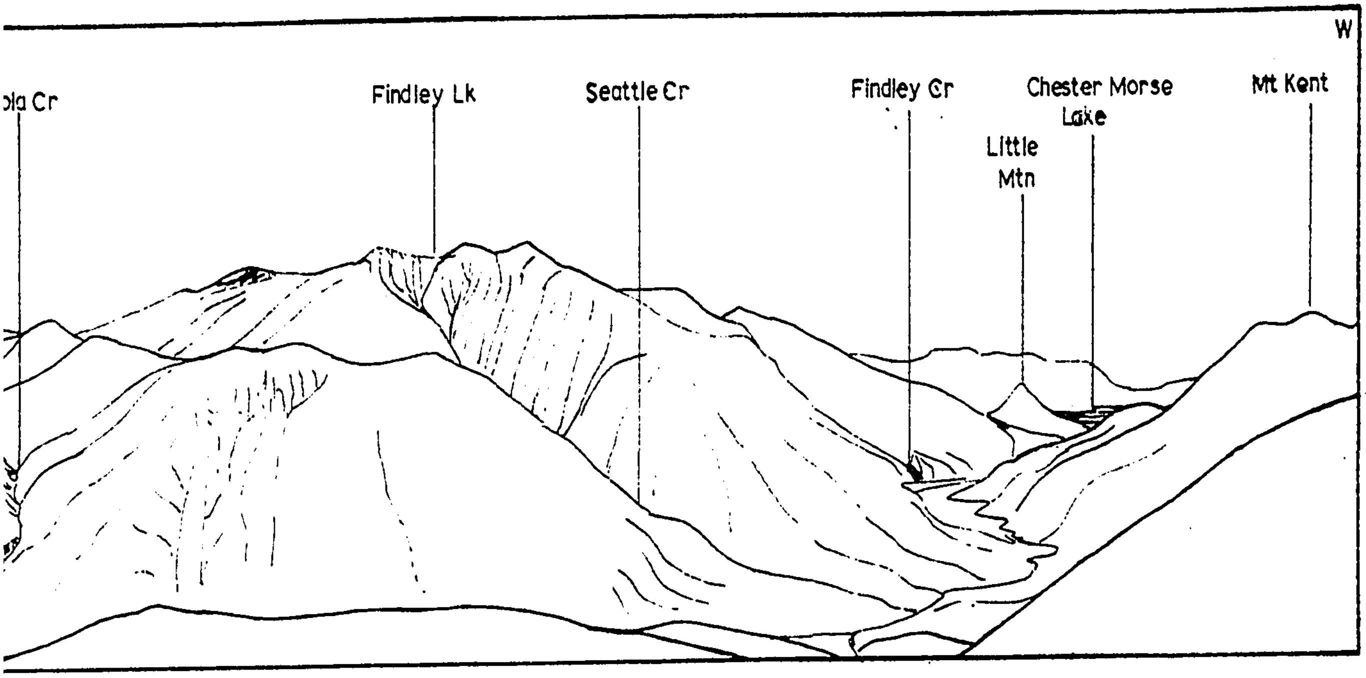
B

Plate 3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Findley Cr
Chester Morse Lake
Mt Kent
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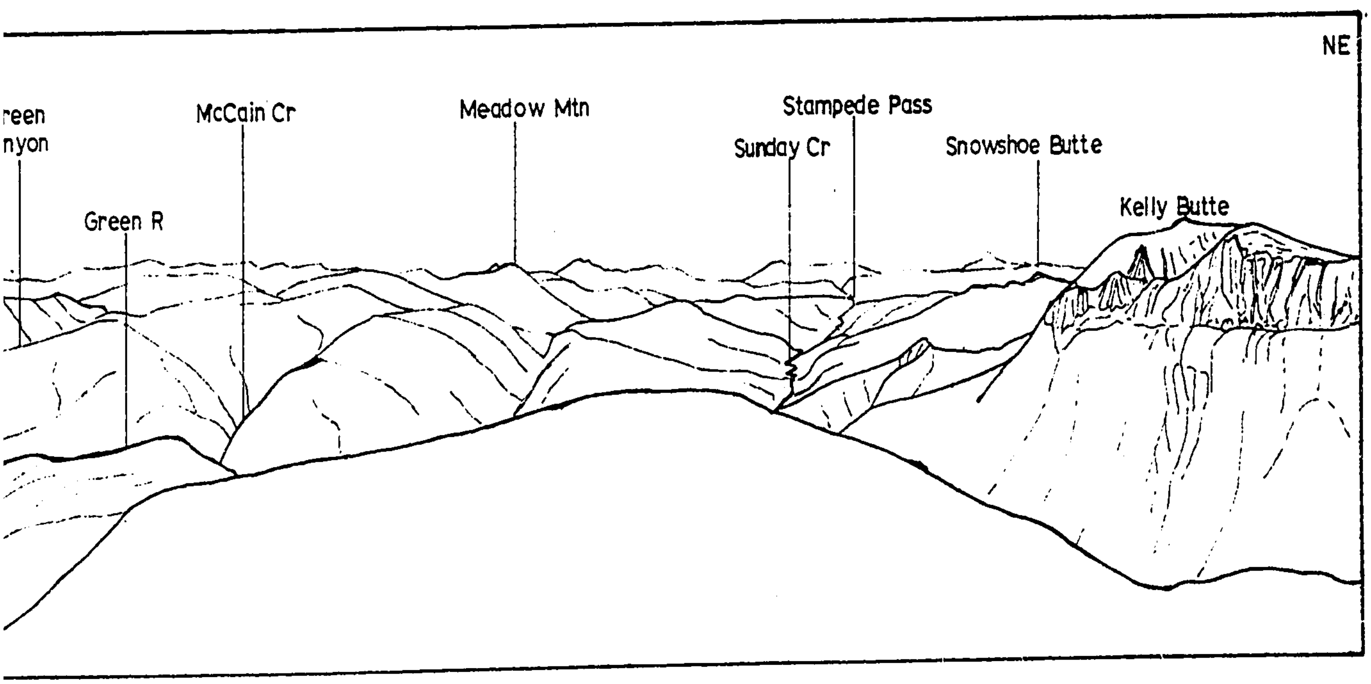
A


NE
reen nyon
McCain Cr
Meadow Mtn
Stampede Pass
Sunday Cr
Snowshoe Butte
Green R
Kelly Butte

B

Plate 3

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INTRODUCTION

Location

The map area (pl. 1) covers the west-central part of the Cascade Range of Washington. It includes the southeastern part of King County and the west-central part of Kittitas County (pl. 4). It spans a part of both flanks of the range, extending from the western foothills to the east side of the upper Yakima River valley, about midway on the eastern slope of the range. The east-west distance is about 30 miles. The Cascade crest trends through the area from Silver Peak, located about 4½ miles south of the Snoqualmie Pass, southward to Naches Pass for a distance of about 20 miles. The western edge of the area lies 25 miles east of Seattle and the eastern edge lies 8 miles west of Cle Elum.

Access.--U.S. Highway 410 follows the White River along the southern edge of the area. U.S. Highway 10 passes through the eastern edge of the area in the upper Yakima River valley. The Northern Pacific Railroad extends along the Green River valley to Stampede Pass and thence southeastward along the Yakima River valley. The Chicago, Milwaukee, Saint Paul and Pacific Railroad follows the west side of the Yakima River valley.

The Cedar River Watershed of the City of Seattle and the Green River Watershed of the City of Tacoma lie within the area.

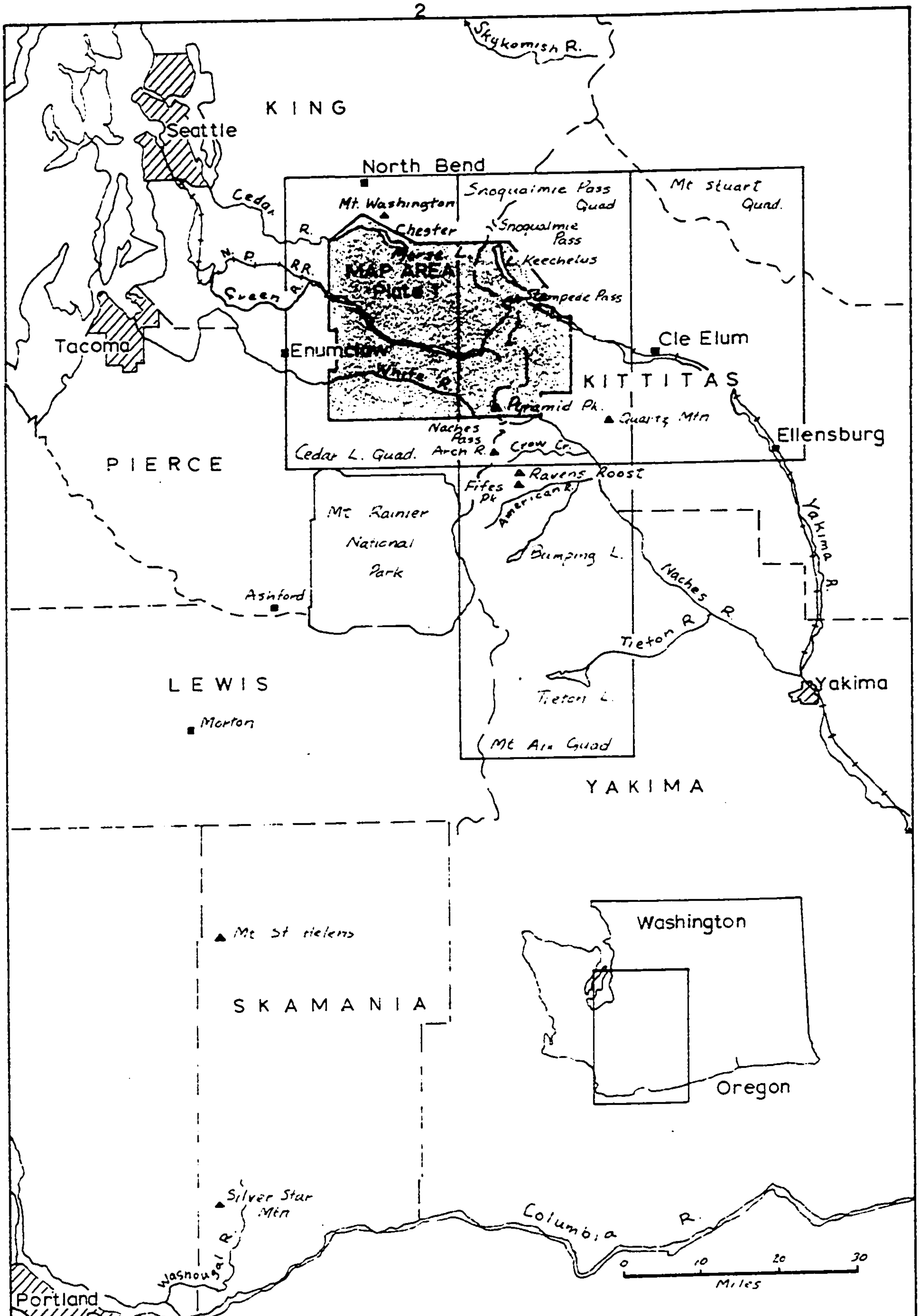


Plate 4 Index Map of South-central Washington

Both watersheds are serviced by an extensive road system. Permission to enter the Cedar River Watershed must be obtained from the Sanitation Engineer of the City of Seattle. Access is granted through the Forestry Division Headquarters at Cedar Falls, about 6½ miles south of North Bend. The City of Seattle also maintains the road along the Bonneville Power Administration right-of-way which enters the map area at Kangley and follows the valley of the North Fork of the Green River southeastward to near Eagle Gorge where it joins with the roads of the Green River Watershed. Permission to enter the Green River Watershed must be obtained from the Sanitation Engineer at Tacoma and the Weyerhaeuser Company at the White River Mill on U.S. Highway 410 about 2 miles east of Enumclaw. The Green River road begins at Cumberland, west of the area and about 6 miles north of Enumclaw, and extends along the south side of the river. The Weyerhaeuser Company maintains gates on the road in sec. 27, T. 21 N., R. 7 E., west of the map area and in sec. 9, T. 20 N., R. 9 E., just north of the bridge across the Green River. The City of Tacoma maintains a gate in sec. 26, T. 21 N., R. 8 E., near Eagle Gorge. The Army Corps of Engineers maintain access to the Howard A. Hanson dam, located in sec. 28, T. 21 N., R. 8 E. Their road follows the north side of the Green River, extending from the Tacoma purification plant to the dam. They maintain gates at the plant and at the road junction with the Bonneville Power Administration road in sec. 27. The Weyerhaeuser

Company also maintains roads in the McDonald Point area located between the Green River and the North Fork of the Green River, in the Coal Creek drainage basin and Grass Mountain area, and the Smay Creek drainage basin. The U.S. Forest Service maintains other graded roads in the area. The Scott Paper Company, which has offices at Lester, has a system of logging roads in the Snow Creek drainage basin and Snowshoe Butte area. Many of the logging roads have been constructed since 1959, the date of the map (pl. 1), and are not shown on it.

The intervening areas are locally accessible by trail. The Pacific Crest Trail follows the crest of the Cascade Range through the map. It is accessible from U.S. Highway 10 and the U.S. Forest Service road at Stampede Pass as well as from the many logging roads in the drainage basins adjacent to the crest. A trail extends from the Cedar River near Bear Creek northward to Mount Gardner and thence eastward along the divide between the Cedar and Snoqualmie Rivers to the crest at Tinkham Peak. The several trails shown on the map in the vicinity of Lester are not traversable for their entire lengths. Good trails lead from areas of Blowout Mountain, Pyramid Peak and the Naches Pass into the upper drainage basin of the Naches River. The trail along the top of Huckleberry Mountain is discontinuous. The Bone Lake area north of Greenwater is accessible by the Christoff trail, beginning at the Greenwater River Camp, about one mile east of Greenwater.

Method of mapping

The field mapping was primarily reconnaissance. It was mainly conducted along road traverses. Traverses were also made along the trails, a few ridges and streams. Aerial photographs were studied throughout the course of the field work for location of outcrops, tracing contacts and interpretation of structure. All data were plotted in the field on advance U.S. Geological Survey topographic prints, scale 1:24,000. Data from aerial photographs were transferred to the topographic sheets. Subsequently, the information was transferred to the base map (pl. 1) of the North Bend Ranger District, Snoqualmie National Forest, 1959, scale 1:62,500. A few place names and locations on the map have been corrected or added to agree with the recently published topographic quadrangles. An index map to the published U.S. Geological Survey topographic quadrangles covering the area is shown on plate 1. The elevation points on the geologic sections (pl. 2) were taken from the topographic maps.

The area was surveyed briefly from airplane flights made in 1957 and 1962.

All the stratigraphic sections were measured in the field by pace and compass. The intervals between stratigraphic units were calculated and the stratigraphic sections were checked for thicknesses on the topographic maps. The stratigraphic sections are described in Appendix A.

The sketches were redrawn from color photographs and from field sketches.

The locations of the important outcrops are listed in Appendix B. A location in the text, followed by a letter and number, refers to the list in the appendix. The designation P4 indicates that the location is the fourth listed under the Puget Group.

Previous geologic investigations

The previous geologic investigators in the map area (pl. 1) are briefly noted below. Their contributions to the understanding of the stratigraphy of the Tertiary rocks are discussed later in the report.

The initial geologic investigation was conducted by Smith and Calkins (1906) as a part of their study of the Snoqualmie Quadrangle.

Fuller (1925) mapped the Cedar River area and extended the rock units of Smith and Calkins westward.

Mackin (1941) recognized that the embankments at the mouths of the Snoqualmie and Cedar Rivers were caused by a glacier which occupied the Puget Sound lowland to the west of the map area.

Warren and others (1945) mapped the extreme western edge of the map area as a part of a study of the King County coal fields.

Cary (1954) reported on the geologic and engineering problems in the construction of the Howard A. Hanson (Eagle Gorge) dam on the Green River.

Foster (1955, 1957, and 1960) mapped the northeastern corner of the map area.

Crandell and Waldron (1956) recognized and traced the Osceola Mudflow which originated on the northern flank of Mount Rainier and descended the White River valley to the Puget Sound lowland at Enumclaw.

Stout (1959) mapped the southeastern corner of the map area.

Waters (1961) attempted to correlate some of the rocks in the Green River valley, at Stampede Pass and along Lake Keechelus with the formations recently established by Fiske (1960) in Mount Rainier National Park.

An index map showing the extent of previous geologic mapping in the map area is shown on plate 1.

Present investigation

The writer, as a geologist for the Northern Pacific Railway Company, conducted his first work in the Lake Keechelus area in 1957. The present investigation was started in 1960 when, as a part of the expanding geologic program of the Northern Pacific Railway Company to evaluate the mineral potential of its lands, a study was begun of the Green River drainage basin. In the field seasons of 1961 and 1962 the study was expanded to cover an area of about 800 square miles, of which the map area (pl. 1) is only a part. The major part of the 1962 field season was spent in tracing stratigraphic units and structures, measuring stratigraphic sections, and detailed mapping of potential economic mineral areas. The report herein concerns only the descriptive geology.

Only a brief petrographic study of the rocks has been made. The mineral percentages have been determined by visual estimations. The rock colors have been compared as close as possible to the Rock-Color Chart (Goddard et al., 1951).

The leaf fossils and imprints are deposited in the Division of Geology and Paleontology, Thomas Burke Memorial Washington State Museum, University of Washington, as Lot no. 143. Representative petrographic thin sections are filed in the Department of Geology, University of Washington, as Lot no. 143. Also, many hand specimens of the rocks are filed in the Thomas Burke Memorial Washington State Museum. The leaf fossil, thin section and specimen localities are listed in Appendices B and C, respectively.

Acknowledgements

The writer extends special thanks to the following personnel of the Northern Pacific Railway Company who supported and encouraged the field investigation, loaned aerial photographic coverage of the area, and provided base maps: George R. Powe, Assistant General Manager and Manager of Mining Properties, Ernest E. Thurlow, Chief Mining Geologist, Glen A. Boyd, Jr., District Mining Geologist, Harry O. Tutmark, pilot-photographer, and William L. Rice, Mining Geologist, who ably assisted the writer in the field in 1961. The writer was also capably assisted in the field by Stanley J. Luft, 1957, Anton Wodzicki, 1960, and William S. Bliton, 1962.

The writer is indebted to Joe Monahan, Seattle Division of Forestry at Cedar Falls; Monte Rodde, Weyerhaeuser Company, White River Mill; Anton Brozovich, U.S. Forest Service, Lester; and the Scott Paper Company, Lester, for their courtesies in facilitating the field work.

The writer is particularly grateful to Professor Howard A. Coombs, who has supervised the dissertation, for his encouragement and stimulating criticisms, to Professors Joseph A. Vance and Bates McKee for their aid in the petrographic studies and criticisms, and to Professor V. Standish Mallory for his study of the collections of fossil leaves and criticisms.

And lastly, the writer is indebted to his wife, Jean, for her encouragement, patience, field assistance, criticisms of the text, and financial support.

GEOGRAPHY

Topography and drainage

The map area (pl. 1) includes three westward-trending ridges which join on the east with the north-south-trending crest of the Cascade Range. The westward-trending ridges are separated by the valleys of the Cedar, Green and White Rivers. The Cascade crest separates these drainage basins from the basin of the Yakima River to the east. The Yakima River drains the east side of the Cascade Range.

The ridges terminate abruptly at the western foothills and rise gradually in altitude to their union with the Cascade crest. The highest peaks lie along the Cascade crest. Blowout Mountain at 5,735 feet, in the southeastern corner of the map, is the highest point. Pyramid Peak, to the southwest of Blowout Mountain, is 5,715 feet. Silver Peak, 5,605 feet, Tinkham Peak, 5,695 feet, and Meadow Mountain, 5,449 feet, lie to the north along the crest. Other high points are Mount Lindsay, 4,380 feet, located south of Chester Morse (Cedar) Lake, Cougar Mountain, 4,504 feet, in the central part of the area, Grass Mountain, 4,382 feet, in the southwestern corner, Huckleberry Mountain, 4,901 feet, in the south-central, and Kelly Butte, 5,409 feet, south of Lester. Within the map area the Cascade crest lies at its lowest average altitude of any part of its length between the Canadian border and Mount Adams.

The major passes are Yakima Pass, 3,575 feet; Stampede Pass, 3,710 feet; Tacoma Pass, 3,450 feet; and Naches Pass, 4,900 feet. Only Stampede Pass is traversable by road.

The Cedar, Green, White and Yakima Rivers flow in broad valleys. Their gradients are very gentle, averaging about 40 feet per mile.

The lowest points of altitude occur along the rivers where they leave the edge of the map: Cedar River, 760 feet; Green

River, 840 feet; White River, 1,200 feet; and the Yakima River, 2,173 feet.

Climate

The climate is humid and temperate. It is influenced by the proximity of the area to the Pacific Ocean and the moisture laden, westward prevailing winds. The winters are characteristically cool and wet; the summers are dry and mild. At Chester Morse Lake the temperature monthly average is from 34.4° - 60.3° F., averaging 47.6° F. annually; the precipitation ranges from 2.35 - 15.69 inches per month, averaging 104.30 inches per year. At Stampede Pass the average monthly temperature range is 23.7 - 56.9° F. with the annual average 39.9° F. Here the precipitation varies monthly from an average of 1.29 - 14.66 inches and averages 93.60 inches per year. On the eastern slope the precipitation and temperature moderate. At Lake Keechelus the temperature averages are 25.8 - 60.2° F. per month, averaging 42.7° F. per year, and the precipitation ranges from an average of 2.35 - 12.57 inches per month, with a yearly average of 68.07 inches.

Vegetation

The map area spans the Humid Transition (1,000 - 3,500 feet), the Canadian (3,000 - 5,000 feet) and the Hudsonian (4,500 - 6,500 feet) life zones. Only the higher elevations lie in the Hudsonian Zone. Dense forests characterize the lower zones.

Douglas-fir and western hemlock predominate in the lower zone and true firs in the Canadian Zone. The undergrowth is dense and impassable in the second growth forest but is sparse beneath virgin timber.

Mixed forest types predominate on the eastern slope. Here the undergrowth is passable and locally absent. Timberline lies at about 5,000 feet.

Bedrock exposures

The exposures are generally fair to poor. Thick soil and organic litter mantle large areas, especially in the forests. Glacial drift covers large areas in the northwestern part of the area and along the Yakima River valley. The best exposures are in resh cuts along the logging roads. Many of the cuts greatly deteriorate over a year's time. Many large cuts along the railroads and highways are excellent. The most continuous exposures occur atop the higher peaks and ridges--Tinkham, Abiel, and Silver Peaks; Meadow, Cougar, Blowout and Huckleberry Mountains; and Kelly Butte. The area east of Blowout Mountain and south of Big Creek, in the southeastern part of the area, is sparsely timbered and has some of the best and most continuous exposures in the central Cascade Range.

Habitation

Several communities of population less than 100 persons occur in the area. Cedar Falls is the headquarters for the Forestry

Division, City of Seattle, Selleck and Kangley are now inactive coal-mining communities. Greenwater is a resort along U.S. Highway 410. Lester was an important railroad town, before the advent of the diesel locomotive. All the railroad shops have been removed. It is now a permanent logging camp for the Scott Paper Company. Upham, located along Cabin Creek in the southeastern part of the area, is a logging camp for the Boise Cascade Corporation. The summit of Snoqualmie Pass, located about 3 miles north of the northeastern corner of the map, is a way-stop for travellers and a winter recreation center.

Commerce

Logging is the major commerce in the area. The Weyerhaeuser Company operates in the White and Greenwater River areas, Mountain Tree Farm Company in the Cedar River Watershed, Scott Paper Company in the upper Green River, and the Boise Cascade Corporation in the upper Yakima River area. In addition there are a few private logging operations.

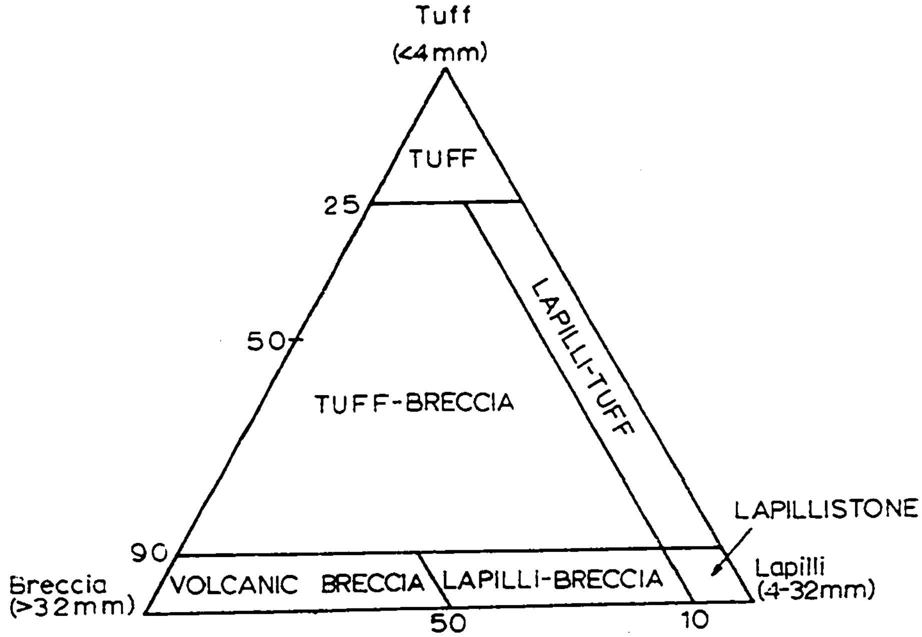
Most of the area serves as the major source of water for the cities of Seattle and Tacoma. For this reason access is restricted as a precaution to insure the purity of water.

DESCRIPTIVE GEOLOGY

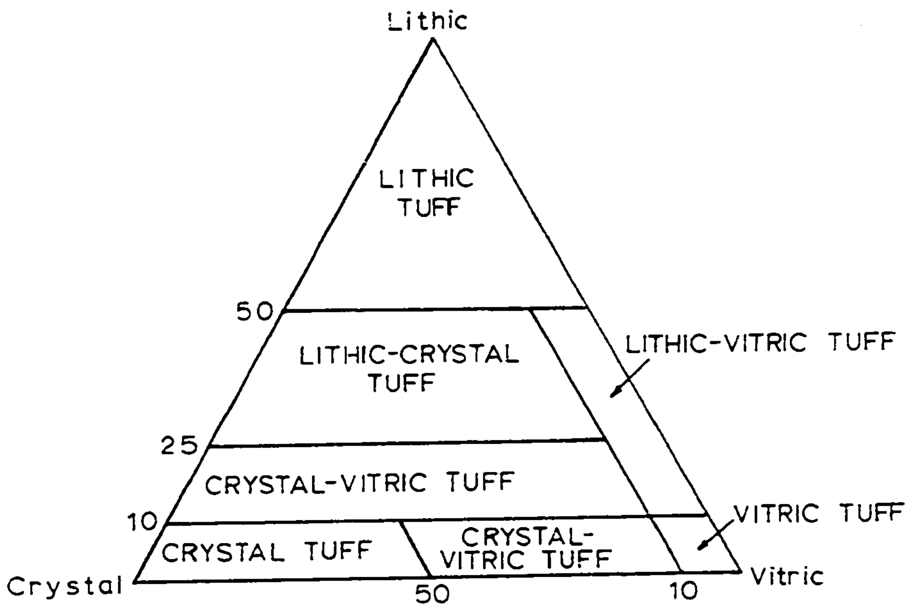
Classification of Volcanic Rocks

Nomenclature of fragmental volcanic rocks

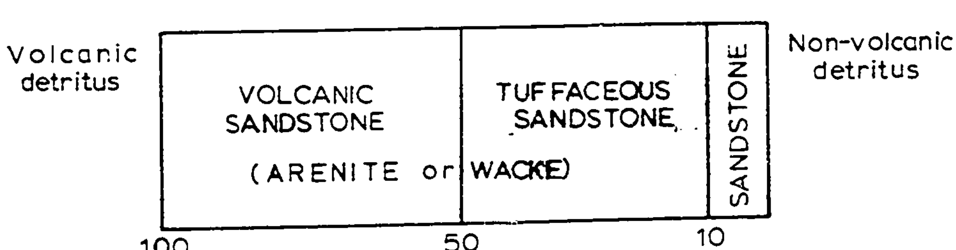
The nomenclature of fragmental volcanic rocks adopted in this report closely follows the terminology of Wentworth and Williams (1932). In order to make the terminology more useful in the field the writer defines the volcanic rock on the percentage volume of its constituents. These percentages are shown in the triangular diagram in plate 5A. Many references on the classification of volcanic rocks have been studied but few geologists have attempted to place parameters to the classification of fragmental volcanic rocks. Wargo (1960) proposed a similar triangular diagram but defined tuff as containing 90 percent or more constituents less than 4 mm in size. A tuff deposit with so few size variations is rare among the rocks of the Keechelus Volcanic Group. The lower percentage limit defined for tuff-breccia is in accord with the A.G.I. Glossary (1960, p. 306). The writer recognizes Fisher's (1961, p. 1412) use of the terms lapillistone and lapilli-tuff but fits the terms to his parameters. The definitions (pl. 5A) proved useful in mapping the Keechelus volcanic rocks, especially in attempting to trace a specific lithologic unit and to show its relationship to the enclosing units.



A. Classification of fragmental volcanic rocks



B. Classification of tuffs



C. Nomenclature of sandstones with volcanic detritus

Plate 5 Classification and nomenclature of fragmental volcanic rocks

The classification makes no distinction between volcanic rocks of autoclastic, pyroclastic or epiclastic origin. It will accommodate the definition of volcanic breccias by Parsons (1960). It is also in agreement with the classification proposed by Wright and Bowes (1963, p. 83), except they have placed a lower size limit. The adjectives, essential, accessory and accidental (Wentworth and Williams, 1932), denoting the principle composition of the fragments can be added as modifiers to the rock name.

The compositional range of the tuffs is shown in plate 5B. The diagram is similar to that proposed by Cook (1960, p. 33). His distinction between crystal-vitric and vitric-crystal tuff is eliminated because this modification is contrary to common petrographic usage. The classification of tuffs is useful for both field and petrographic study. Lithic-crystal tuff is a tuff which contains more crystals than lithic fragments and a groundmass composed of a low percentage of vitric constituents. Cook (1962, p. 15) considered pumice as a vitric constituent but herein if pumice exceeds 10 percent volume of the tuff, the rock is modified by using pumice as an adjective. The classification of tuffs can also be applied as adjectives to the description of the tuffaceous matrix of lapilli-tuff and tuff-breccia. For example, a lithic-crystal tuff-breccia is a tuff-breccia in which crystals exceed the volume of lithic fragments and both exceed the volume of vitric constituents in the tuff matrix.

The classification of sandstones containing volcanic detritus is shown in plate 5C. Volcanic sandstones with as much as 90 per cent volcanic detritus are commonly difficult to distinguish from a tuff. Here a generic origin must be determined; the presence of the sandstone interstratified with fluvially deposited beds may be a clue.

Description of rock types

Lava flows, breccia flows, tuff-breccias, tuffs and volcanic sediments are the major rock types in the Tertiary volcanic strata in the west-central Cascade Range. Each rock type described is given below in order to acquaint the reader with their general features--composition, outcrop habit, coloring, jointing, contact relationships, areal distribution and stratigraphic significance. The features serve as criteria for the identification of the rock types. Reference will be made to this discussion in the descriptions of the rock units. Reference will also be made in this discussion to some of the plates which occur later in the report.

The volcanic stratigraphic units are characterized by unconformable relationships; conformable contacts are rare. The units are lenticular in cross-section and most, where they can be followed any distance in the field, are lobate in areal extent. The units are overlapping in their distribution.

Lava flows.--Lava flows are easily recognized in the field.

They are fairly resistant to erosion and commonly crop out as ledges along ridge slopes. They may be traceable for short distances in logged and in some forested areas. Their stratification is the best aid to recognizing structure. The flows can be distinguished from the other rock types by (1) their resistance to erosion, (2) dark color, and (3) uniform composition. Additional features are vesicular and amygdaloidal textures and flow-layering, which may be accentuated by jointing. The rocks are rarely scoriaceous but the vesicles are commonly attenuated in the direction of flow. Flow units range in thickness from 5 to 300 feet, the average being about 30 feet. A further aid to the recognition of lava flows is the association of lava flows with breccia flows, as is shown in plate 6A.

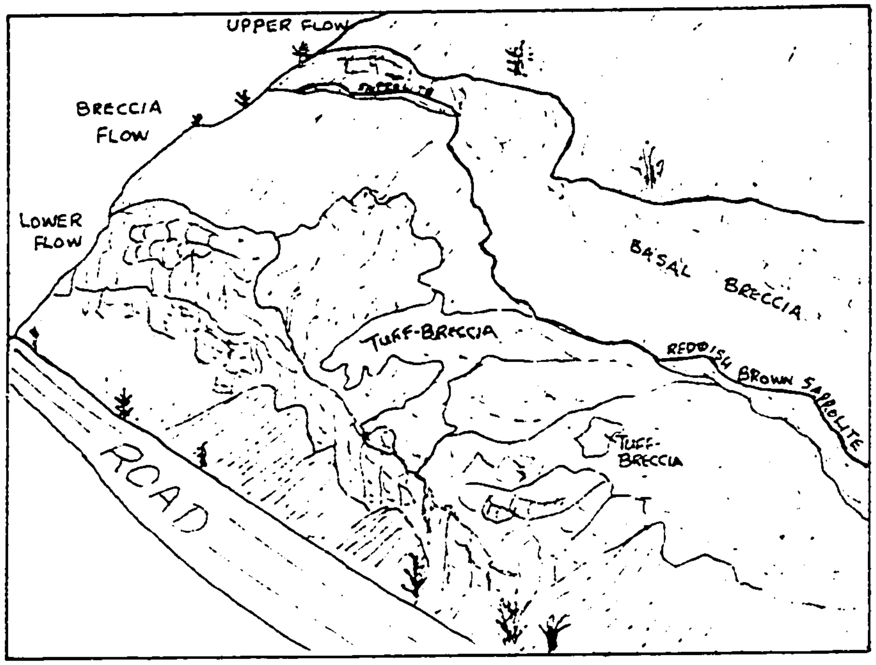
The jointing of the flow rock is blocky to platy to columnar. The blocky jointing is regular to irregular (pl. 6A). Locally the blocks are rounded and the joint faces are curved. The faces are variable in size. The rounded blocks decrease in size locally to form rounded dice, which are tightly fitted together and weather to form a rubbly outcrop. The rounded blocky jointing is transitional with ball-like jointing commonly associated with columnar jointing. Platy jointing is disc- to wedge-shaped.

Columnar jointing produces crude to well-formed columns. Locally they pinch and swell; extremely irregular jointing produces wavy columns. The columns may be as small as 4 inches to

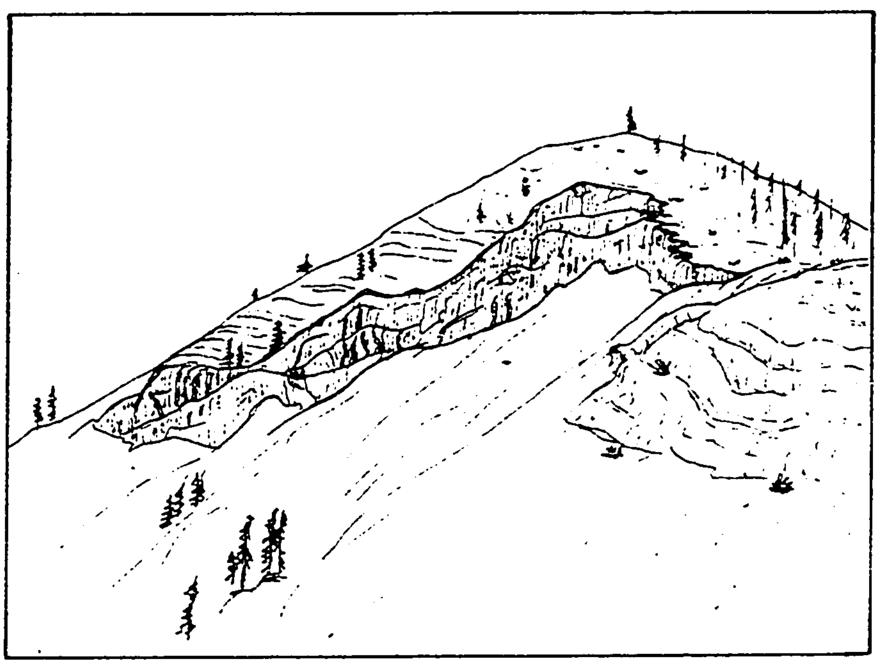
PLATE 6

A. Sketch of outcrop of interstratified lava and breccia flows and minor amounts of tuff-breccia in the Eagle Gorge Andesite, exposed in a railroad cut west of Humphrey in the NW¼NE¼NE¼ sec. 12, T. 20 N., R. 8 E.

B. Sketch of disconformable stratification between a 45-foot section of lava flow units and volcanic sediments in the Huckleberry Mountain Formation on northeast flank of Blowout Mountain in the NE¼NE¼NE¼ sec. 14, T. 19 N., 12 E. (see stratigraphic section in Appendix A).


UPPER FLOW
BRECCIA FLOW
LOWER FLOW
BASAL BRECCIA
TUFF-BRECCIA
REDDISH BROWN SAPROLITE
TUFF-BRECCIA
T
ROAD

A



B

PLATE 6

as large as 10 feet in diameter. The columns occur singly or in clusters, joined as twins to form "double barrels" or as poly-column clusters. Splintery columns are rare; they are irregular, have twisted faces, of which at least one has a prounounced face, and range in diameter from 2-10 inches.

Well developed flow-layering which is locally contorted and brecciated is displayed by silicic flows.

The contacts of the flow units are very irregular (pl. 6A). A few excellent outcrops (pl. 6B) reveal very well disconformable contacts. Both top and bottom contacts are commonly marked by brecciated zones which are believed to be caused in part by auto-brecciation of the flow during its movement and in part by cata-clastic brecciation along bedding planes during deformation of the strata. The lava flows are gradational vertically with breccia flows. If the breccia has been altered, which is common in the map area, the contact between flow units is very difficult to dis-tinguish. The lava flows commonly grade laterally and terminate at breccia flows.

The flow units are lenticular in cross-section; many are probably valley-fill flows. The lack of continuous outcrop pre-vents determination of their total distribution and direction of movement. Most appear to be lobate in plan. The flow units of andesitic composition are most widespread; those of silicic com-position are least widespread. All flows are restricted areally;

that is, they are not "layer-upon'layer" flows characteristic of the Columbia River Basalt flows.

The lava flows are one of the more important stratigraphic markers, mainly because they are most easily traced in the field and because they form a sequence which can be delineated and designated as a lithologic unit.

Breccia flows.--A breccia flow is a breccia of essentially monolithic flow rock composition, containing fragments of variable size and shape embedded in a comminuted matrix of the same composition. It is flow of breccia. It consists in part of breccia which formed through autoclastic brecciation of lava flow during its movement and block lava. The flow is not a flow breccia (Holmes, 1928, p. 100) because the fragments are not welded together or cemented by the fluid parts of the same flow. The breccia flow differs from a block flow (MacDonald, 1953, p. 182-183) because the fragments tend to be rounded and extremely variable in size and shape, and the flow contains a considerable amount of comminuted matrix. The breccias have been transported en masse as individual units; that is, they may have been hydraulically advanced ahead by the fluidal portion behind or they may have been rafted atop a fluidal interior. They are most common as top or bottom breccia and less common as an intrabreccia of a flow unit. They may also compose an entire flow unit as much as 300 feet thick.

The fragments range in size from coarse-grained sand to blocks as large as 6 feet in diameter. The average size is about 4 inches. They are subangular to rounded and blocky to tabular in shape. Foreign fragments, which constitute less than 5 per cent of the flow, are believed to have been picked up during flowage. Commonly, the breccias are altered and, consequently, are light colored in contrast to the associated lava flows, varying in shades of gray, purple, red, brown, blue and green. Large blocks of flow rock within a breccia flow are unaltered and retain their darker color. The comminuted matrix is commonly yellow to brown and is deeply stained by iron oxides. Zeolites, chalcedony, calcite and hematite are ubiquitous alteration products. Additional alteration products probably include iron-bearing clays--celadonite, natronite, saponite and chlorophaeite (Fiske, 1960; Waters, 1955, p. 710; 1961), although no attempt was made to distinguish them in the present study.

In outcrop the breccia flows are massive; they reveal no bedding except along their contacts and have no distinctive jointing. Weathering tends to pluck out the soft matrix and undermine the blocks.

Accretionary blocks, 3 to 20 feet in diameter, composed of agglutinated flow rock fragments are rare. The blocks are probably fragments of flow breccia.

The contacts of the breccia flows are very irregular. Locally the contact may be vertical. Shear zones are common between the solid lava flow and the brecciated lava and were probably formed in part by shearing during flowage or by deformation of the strata. Large carbonized tree fragments have locally been incorporated and mascerated in the breccia flow, suggesting some degree of turbulence or roll-over action within the breccia mass as it moved forward. The fluidal interior of a flow unit may override the breccia front. This feature is revealed in an outcrop where the flow layering of the lava flow is parallel to the contact with the underlying breccia but is not parallel to the over-all stratification of the flow unit. Part of the brecciation is due to explosive steam action in areas where a lava flow moved over wet ground or into water (see discussion of Eagle Gorge Andesite).

Breccia and lava flows are integral parts of a sequence of flow units within the map area. The lava flows grade laterally into breccia flows; as the flow units are traced outwards from their source they contain a greater proportion of breccia. However, local variations in the proportion can be caused by a flow having come into contact with water or by the irregularity of the terrain over which the flow had moved.

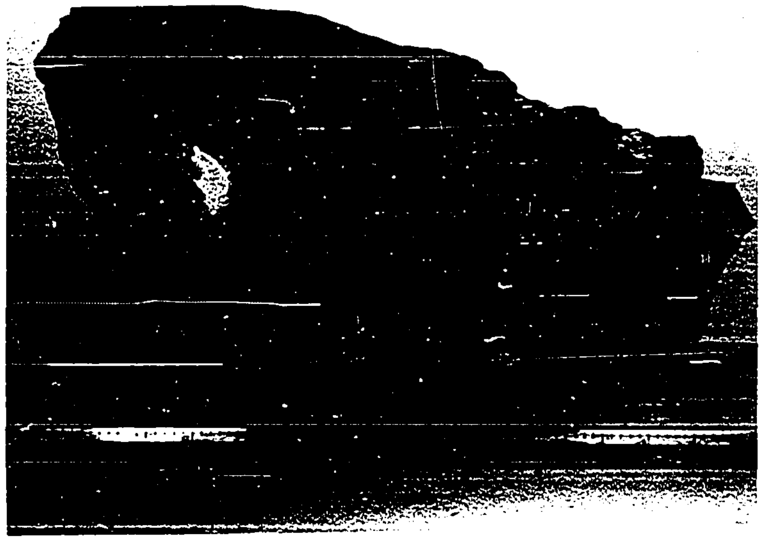
Tuff-breccia.--The discussion of tuff-breccia also pertains to lapilli-tuff, lapillistone, lapilli-breccia and volcanic breccia. The tuff-breccias occur as massively bedded strata which superficially resemble breccia flows. However, they can be

PLATE 7

Tuff-breccia and volcanic sediment

A. Lithic-pumice tuff-breccia of the lower part of the Bear Creek Mudflow Member of the Huckleberry Mountain Formation, exposed along the Northern Pacific Railroad in the SE¼SE¼SE¼ sec. 20, T. 21 N., R. 8 E. Dark-colored fragments are aphanitic flow rock. One dark fragment in upper center is a vitrophyre. Lighter-colored fragments are pumice, some of which are attenuated; all are altered.

B. Well-bedded volcanic sediments, consisting mostly of lapilli-tuff and volcanic sandstone, in the lower part of the Snow Creek Formation at the type section (SE¼NW¼NE¼ sec. 35, T. 21 N., R. 11 E.) west of Stampede Pass. Slump structure occurs at the hammer in the center. Slumping is to the left (southwestward). See stratigraphic section in Appendix A.



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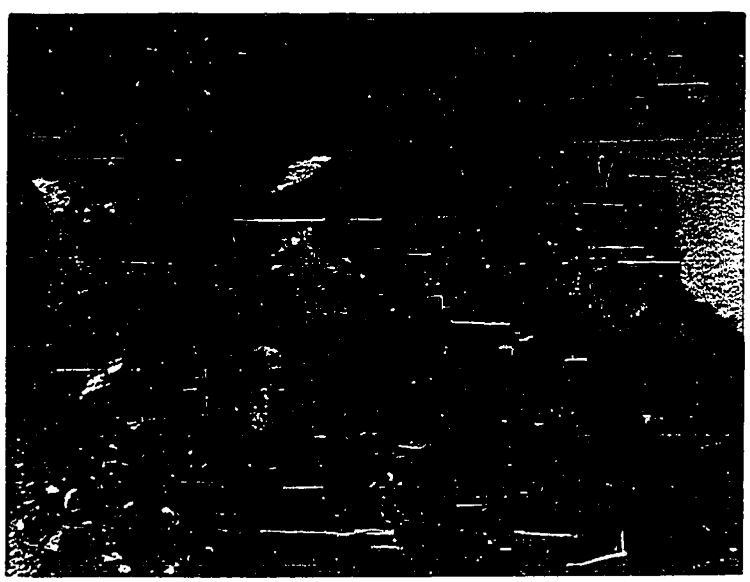


B

PLATE 7

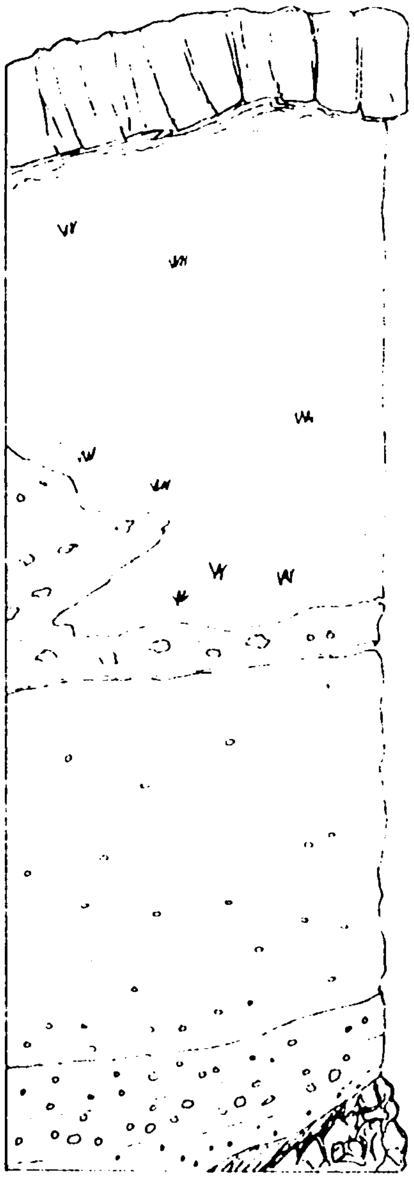
distinguished by their heterolithic composition, the inclusion of pumice fragments and tuff, and the presence of a fine matrix which is neither sandy nor granular and is of a composition different than lava flow (pl. 7A). The clasts are angular to rounded, the average being subrounded. Their average size is 2 inches, smaller than the fragments in breccia flows. A fine tuff-breccia consists predominantly of fragments about 1-2 inches in size and is gradational with lapilli-tuff or lapilli-breccia. A well-sorted tuff-breccia consists predominantly of fragments within a narrow size range. The composition of the clasts and matrix is variable. Pumice fragments are common. Lithic fragments consist predominantly of flow rock fragments which vary from porphyries to flow-layered aphanites. In addition there are fragments of tuff and vitrophyre. Crystals are locally very abundant. The tuff matrix is extremely altered; evidence of shards could not be found.

The tuff-breccias are believed to be derived through two modes. Tuff-breccia of mudflow origin (lahar of Mullineaux and Crandell, 1962) have a crude vertical stratification in which the coarser clasts occur in the lower part and grade upward into finer sizes. The upper part of a mudflow unit is generally well sorted. The tuff-breccia grades laterally and is intercalated with volcanic sediments. It has a dense very well-compacted matrix. The fine tuff fills the spaces between angular pumice fragments and breadcrust bombs. Trees may be enclosed in the tuff-breccia. They may occur at various stratigraphic levels and have haphazard orientation, suggesting that the breccia had turbulent flow. Others are flattened and aligned in the same direction along the base of the tuff-breccia, suggesting that the breccia plowed into a stand of timber.

A tuff-breccia of airborne origin is essentially a block-and-ash deposit. It has crude stratification which is draped over the irregularities of the underlying terrain. The clasts consist of abundant pumice and tuff; their size is variable. The coarser fragments are not confined to the lower part. The pumice fragments are not compacted. An airborne tuff-breccia is shown in plate 8.

An airborne tuff-breccia has a variable heat content at the time of its accumulation. With an increase in heat content the tuff-breccia is gradational into a welded tuff. If it were cool, the tuff-breccia would be highly susceptible to fluvial reworking and be redistributed in the form of mudflows or volcanic sediments. A tuff-breccia unit, grading upward from welded tuff to a pumice tuff-breccia of mudflow origin, in which the unconsolidated pyroclastic debris has been reworked, is shown in plate 9. An intensely altered airborne tuff-breccia may be difficult to distinguish from a mudflow.

Tuff-breccias are similar to breccia flows in that they lack distinctive jointing. Weathering tends to produce a slabby



30' lava flow
base has well-developed
columnar jointing

60' covered interval

20' exposed of gray pumice-lithic (boulder) tuff-breccia

50' yellowish-gray lithic-pumice tuff-breccia

[illegible]' tuff-breccia, grades up and into overlying unit

6' lithic (boulder) tuff-breccia

5' massive, yellowish-gray, pumice-lithic tuff-breccia. Maximum lithic fragment size is 8" diameter; larger fragments are better rounded. Maximum pumice fragment size is 4." A few accretionary pumice fragments up to 8" diameter.

dark-gray, reddish-brown-stained, pyroxene andesite porphyry flow

Occurs in Enumclaw Formation. Exposed between Cyclone and West Twin Creeks, in SW 1/4 SE 1/4 SE 1/4 sec. 34, T. [illegible]N., R. 8E.

Characteristics: crude stratification, draped over irregular topography, thin over highs; lacks size distribution; not well compacted; large lithic fragments occur throughout section; long dimension subparallel to bedding.

Plate 8 Columnar section of air-fall tuff-breccia jointing. The slabs peel, leaving a smooth outcrop face. Lapilli-tuffs tend to peel parallel to their bedding but this feature is not criteria upon which to determine their bedding.

Mudflow tuff-breccias are variable in their distribution. Those which are fairly well exposed are lenticular in cross-section suggesting that they had filled valleys. After descending several adjacent valleys a mudflow may spread out laterally and coalesce in an area of low relief, similar to the lobate-shaped terminal part of the Osceola Mudflow (Crandell and Waldron, 1956). The airborne tuff-breccias, in contrast, may be local in extent, up to 5 miles from their sources.

<u>Tuffs</u>.--Tuffs consist predominantly of vitric clasts, crystals, pumice fragments and minor amounts of lithic fragments. The constituents range in size and percentage locally to form lapilli-tuff, lapilli-breccia and tuff-breccia. Fluvial or lacustrine deposits of similar material are considered as volcanic sediments.

Deposits of tuff are recognized as accumulations of either ash-flow or air-fall. The deposits have a variable heat content at the time of their accumulation. If the heat content exceeds the minimum welding temperature, the deposit may contain a zone of partially to intensely welded tuff. Deposits which form extensive sheets are ignimbrites. They consist of welded and nonwelded

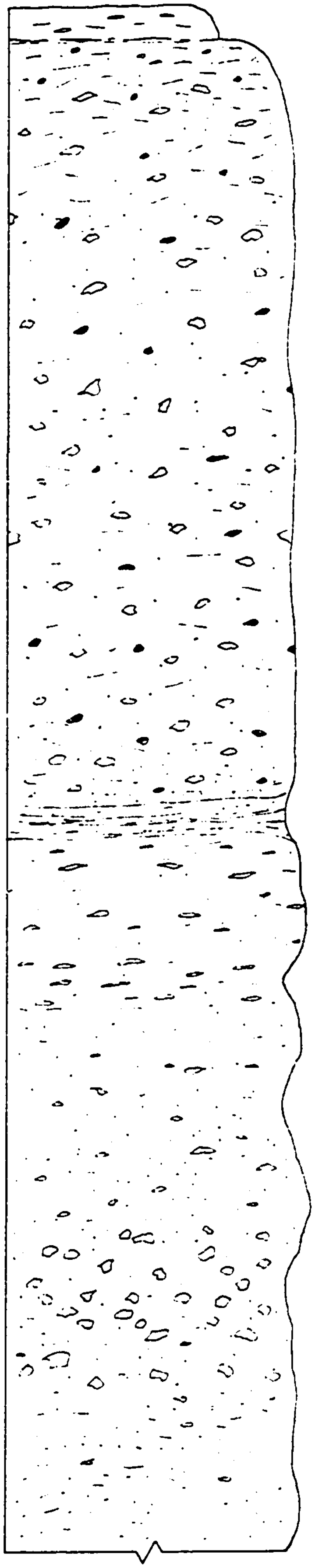


Plate 9 Columnar section of ignimbrite and overlying mudflow

tuff (Mackin, 1960, p. 86; Cook, 1962, p. 13). A single tuff deposit which grades upward from a nonwelded zone at the base through a partially to intensely welded interior zone to a nonwelded zone at the top is a simple cooling unit (Smith, 1960, p. 157). Successive deposits of tuff may form a simple unit if they accumulated rapidly and there was no interruption in their cooling history. Interruptions in the accumulation of a deposit are revealed by layers within the deposit of pumice, pyroclastic material of different composition and volcanic sediment, or by an erosional unconformity. Such a deposit is a composite ignimbrite.

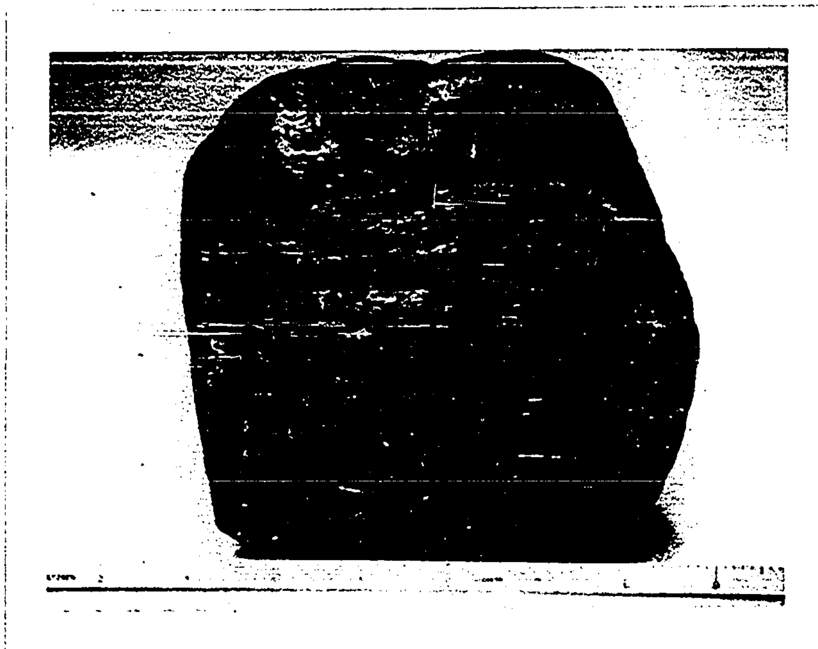
Ignimbrites of ash-flow origin are lenticular in cross-section and appear to have been confined to valleys; however, they may descend adjacent valleys and coalesce in broad areas to form extensive sheets. In the west-central Cascades they are andesitic in composition and are characterized by zones of intense welding, forming a vitrophyre (pl. 10). In contrast, ignimbrites of ash-fall origin are of wide extent and mantle the topography. They are excellent stratigraphic markers in the Cascade volcanic province. They are partially welded and are dacitic in composition (pls. 17 and 18). They tend to be well sorted areally with respect to their source. Local thick accumulations may have formed in depressions by flowage of the unconsolidated ash from adjacent topographic highs. Textures, sizes and volume percentages of the constituents vary internally in the ignimbrites studied. These

PLATE 10

Tuffs

A. Vitrophyre from the intensely welded zone of the Sunday Creek Tuff Member of the Snow Creek Formation exposed at the type section. Rock consists largely of black glass and minor amounts of crystals, and lithic and pumice fragments; light-colored fragments are pumice.

B. Slab of partially welded andesite pumice crystal-vitric tuff in the Rack Creek Tuff Member (unit c in stratigraphic section, Appendix A) of the Huckleberry Mountain Formation, exposed in the NW¼NE¼NE¼ sec. 31, T. 21 N., R. 8 E. Dark-colored lenticular fragments are porphyritic pumice. Scattered fine black fragments are vitrophyres. Mottled patches are probably the result of partial devitrification.



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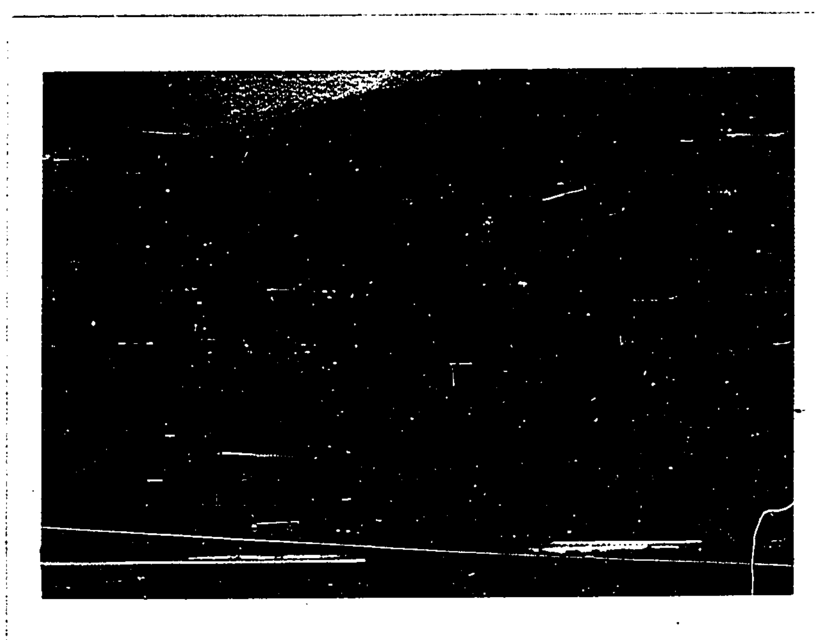


B

PLATE 10

differences aid in distinguishing various units within an ignimbrite.

The bedding within a tuff is revealed by flattened pumice fragments or less commonly by the lineation of crystals and lithic fragments. Compaction produces a eutaxitic layering. The tuffs range in color from black to brownish gray to greenish gray. Altered tuffs are brown to green in color.

Moderately to intensely welded tuffs have a blocky to crude columnar jointing. Disc-shaped platy joints are rare except in the moderately welded zone above the vitrophyric zone in an ignimbrite (see discussion of Sunday Creek Tuff Member of Snow Creek Formation). Weathering of partially welded tuffs (those showing incipient eutaxitic layering) produces a slabby jointing.

The tuffs weather similarly to tuff-breccias. The vitrophyre zone is the most resistant and crops out similarly to a lava flow.

Volcanic sediments.--A sediment with more than 50 percent admixture of volcanic detritus constitutes a volcanic sediment. The sediments consist predominantly of lapilli-tuff, volcanic sandstone and minor amounts of volcanic conglomerate, fine tuff-breccia and lapillistone. They occur as fluvial and lacustrine deposits. Lapilli-tuff and fine tuff-breccia consist largely of pumice and tuff fragments and lesser amounts of lithic fragments and feldspar crystals, embedded in a tuffaceous matrix. The fragments are subangular to rounded. The lithic fragments rarely exceed 5 percent of the volume of the rock. Accretionary lapilli-tuffs (Moore and Peck, 1962) are present. Volcanic and tuffaceous sandstones are distinguished on the basis of whether they contain more or less than 50 percent volcanic detritus (pl. 5C). They are fine to very coarse-grained and consist of tuff and pumice clasts, abundant feldspar crystals and a few lithic fragments. They grade laterally into and are intercalated with siltstone, tuff, and minor amounts of shale. Volcanic conglomerates contain well-rounded clasts, coarser than very coarse grained in size, and less than 10 percent tuff matrix. The volcanic sediments are cemented with clay, calcite, and zeolite.

The volcanic sediments are generally thin bedded. They are well bedded, commonly are graded bedded, and are of uniform thickness across the extent of their outcrop (pl. 10A). Cross bedding is a minor feature. Large scale cross bedding and slump structures are rare. The sediments grade laterally and are intercalated with poorly sorted tuff-breccias of mudflow origin. They are gray, brown and green in color, having been altered similarly to tuff-breccias. They also weather similarly but their bedding is a criterion for distinguishing them from tuff-breccias. Most of the detritus in the finer volcanic sediments of the Keechelus rocks is probably reworked airborne ejecta.

Rock Units

General discussion

The rock units in the area (pl. 1) mapped in the west-central Cascade Range have been divided into stratified and intrusive rocks. The stratified rocks have been subdivided into several formational units (pl. 11) which, from oldest to youngest, are as follows: the Tiger Mountain and Tukwila Formations of the Puget Group; the Guye Formation; the Mount Catherine Tuff (equal in part to the Mount Catherine Rhyolite, Foster, 1960); the Keechelus Volcanic Group which includes the Enumclaw and Huckleberry Mountain Formations, the Eagle Gorge Andesite, the Stampede Tuff and Snow Creek Formation, the "Naches Formation" which is equivalent in part to the Enumclaw and Huckleberry Mountain Formations; the Cougar Mountain Formation; and the "Ellensburg Formation." Surficial deposits of glacial drift, alluvium, and a few landslides are the youngest in the area.

The Puget Group and Guye Formation, of middle to late Eocene age, are a part of the earliest depositional sequence recorded in the area. They are overlain unconformably by the Mount Catherine Tuff, the Keechelus Volcanic Group and the "Naches Formation," a sequence consisting largely of volcanic rocks, ranging in age from late Eocene to Oligocene(?). The Keechelus Volcanic Group is overlain unconformably by the Cougar Mountain Formation of early(?)

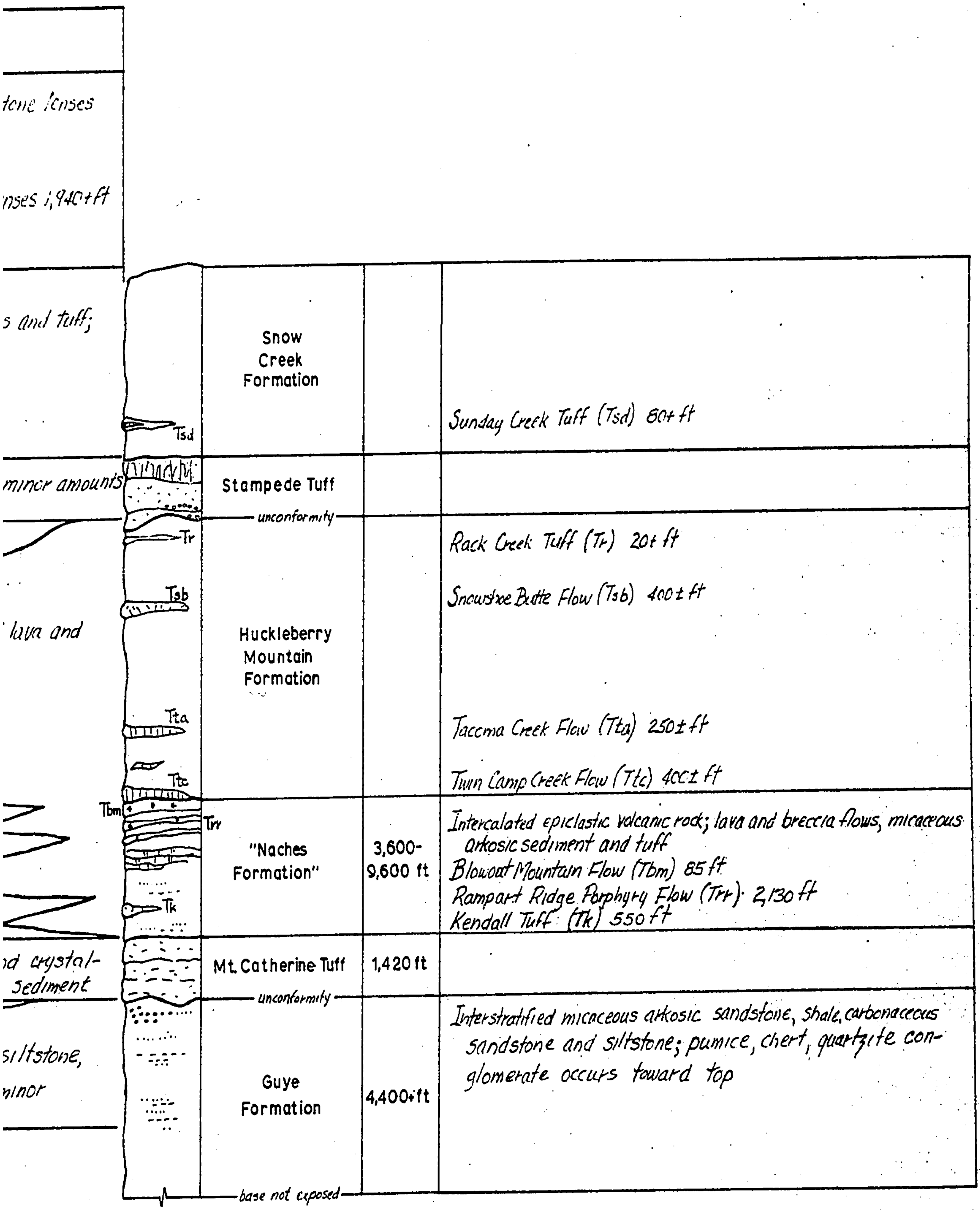
Western Section

Age	Group	Formation	Thickness	Description
Pliocene		"Ellensburg Formation"	360+ ft	Naches Pass lava flows 350+ ft Volcanic sandstone 10+ ft
		— unconformity —		
Early (?) Miocene		Cougar Mountain Formation	3,210-5,300 ft	Lava and breccia flows, boulder conglomerate and sandstone lenses Upper part: lava flows 1,010+ ft Middle part: boulder conglomerate and sandstone lenses 1,940+ ft Lower part: lava and breccia flows 260+ ft
		— unconformity —		
Oligocene (?)	Keechelus Volcanic Group	Snow Creek Formation	3,600-4,800 ft	Tuff-breccia, volcanic sediment, lava and breccia flows and tuff; more flows to west
Eocene	Keechelus Volcanic Group	Stampede Tuff	40-2,820 ft	Composite ignimbrite: dacite crystal-vitric tuff and minor amounts of tuff-breccia
		— unconformity —		
Eocene	Keechelus Volcanic Group	Eagle Gorge Andesite	730-4,150 ft	Lava and breccia flows and subaqueous breccia
		— unconformity —		
Eocene	Keechelus Volcanic Group	Huckleberry Mountain Formation	2,200-11,100 ft	Tuff-breccia, volcanic sediment and minor amounts of lava and breccia flows, and tuff Champion Creek Tuff (Tch) 300+ ft Rack Creek Tuff (Tr) 200-300+ ft Bear Creek Mudflow (Tbc) 1,320+ ft McDonald Point Tuff (Tmp) 250+ ft
Late	Keechelus Volcanic Group	Enumclaw Formation	3,600-9,600 ft	Lava and breccia flows; minor amounts of tuff-breccia, volcanic sediment and tuff Eagle Lake Flow (Tel) 650 ft Cyclone Creek Flow (Tc) 75+ ft
Late		Mt. Catherine Tuff	1,420 ft	Composite ignimbrite: rhyolitic to dacitic vitric and crystal-vitric tuff and minor amounts of silicic volcanic sediment
		— unconformity —		
Middle	Puget Grp	Tukwila Frm	700 ft	Epiclastic andesitic volcanic rock
Middle	Puget Grp	Tiger Mountain Formation	2,100+ ft	Interstratified micaceous arkosic sandstone, siltstone, carbonaceous siltstone, claystone, coal, and minor amounts of epiclastic volcanic rock
		— base not exposed —		

Tbm

Plate 11 Generalized columnar sections

Eastern Section



...nar sections of Tertiary stratigraphic units

Miocene age. Deposition of the Cougar Mountain Formation was followed by extensive deformation and subsequent extensive intrusions of porphyries and the plutons of the Snoqualmie batholith. Local deposits referred to the "Ellensburg Formation" of late Miocene to early Pliocene age rest unconformably on older rocks.

The intrusive rocks are subdivided into hypabyssal intrusions of altered rhyolite, hornblende lamprophyre, altered pyroxene andesite porphyry, and quartz-pyroxene diorite, all of which are believed to predate the emplacement of the Snoqualmie batholith, and transitions between quartz diorite, granodiorite, and quartz monzonite which constitute the southern part of the Snoqualmie batholith. Hornblende dacite porphyry, fresh pyroxene andesite porphyry and fine-grained andesite were intruded after emplacement of the Snoqualmie batholith.

Stratified rocks

Puget group.

Definition.--The name "Puget Group" was originally applied to the brackish water and continental coal-bearing arkosic sandstone and shale in the Puget Sound lowland west of the Cascade Range by White (1888, p. 447). Willis (1898) made the first description of the stratigraphic sections of the "Puget Group." Evans (1912) subdivided the "Puget Group" in the Green River area into a lower Bayne "series," a middle Franklin "series" and an upper Kummer "series" but was unable to correlate his units with those established by Willis. Warren and others (1945) made a detailed map of the King County coal field. They divided the rocks into a lower marine Cowlitz (?) formation (Weaver, 1912, p. 11-13), a middle Eocene volcanic series, and the overlying "Puget Group." Warren delineated intertonguing of the Eocene volcanic series with the sedimentary rocks of the "Puget Group." Waldron (1962) redefined the "Puget Group" to include the Eocene volcanic series in the Seattle area and the overlying coal-bearing rocks. He named the volcanic rocks the Tukwila Formation and the overlying sedimentary rocks the Renton Formation. Vine (1962a) extended the terminology of Waldron to include the Eocene volcanic series and the overlying "Puget Group" previously mapped by Warren in the areas of the Hobart and Maple Valley (7½-min.) quadrangles. In addition Vine subdivided the Cowlitz(?) Formation into the lower Raging River Formation and overlying Tiger Mountain Formation. He redefined the Puget Group to include the lower Tiger Mountain Formation, the middle Tukwila Formation and the upper Renton Formation.

Tiger Mountain Formation.

Distribution and thickness.--The lowest stratigraphic unit in the map area consists of interstratified nonmarine sedimentary rocks, coal beds and minor epiclastic andesitic volcanic rocks. They occur in the northwest part of the map area (pl. 1). They were mapped by Warren and others (1945) as the upper part of their "Puget Group" but are assigned by the present writer to the Tiger Mountain Formation (Vine, 1962a, 1962b) on the basis of their stratigraphic position and similar lithology.

The strata have a minimum exposed thickness of 2,100 feet. The formation has a thickness of 2,000 feet in the Hobart quadrangle, 4 miles northwest of the map area. This thickness does not include the 825 feet of epiclastic volcanic rocks of the Tukwila Formation interstratified with the upper part of the Tiger Mountain Formation.

<u>Lithology</u>.--The rocks of the Tiger Mountain Formation are very poorly exposed. They are deeply weathered and locally covered by thick brushy stands of secondary growth timber and glacial deposits. They consist of light-gray to olive to brown-weathering interstratified nonmarine arkosic to feldspathic micaceous fine- to coarse-grained sandstone, siltstone and shale, carbonaceous siltstone, coal, claystone, and minor well-rounded granule-pebble chert conglomerate. Beds of yellowish-gray to reddish-brown-weathering lithic-pumice lapilli-tuff and coarse-grained pumiceous volcanic sandstone are intercalated near the top. The coarser sandstones are thin- to thick-bedded; the thicker beds are commonly cross-bedded. The finer sediments are laminated to thin-bedded. The beds of volcanic sediments are massive. A coal bed about 7 feet thick and containing many bone partings is exposed in a trench along the McDonald Point road (P 1, see Appendix A). Other coal beds are poorly exposed in cuts along

the road in the same area. Coal has been mined from at least two beds in the presently abandoned Pocahontas mine (P 2). The probable extension of the Durham-Kanaskat flint-clay bed (Warren and others, 1945; U.S. Bureau Mines, 1945) is exposed in a trench along the McDonald Point road (P 3). The bed is about 5 feet thick and consists of gray oolitic claystone. It overlies a 5-foot thick coal bed.

<u>Contact relations</u>.--The base of the formation is not exposed in the map area. Vine (1962a, p. 12) defined the base of the Tiger Mountain Formation (Puget Group) as conformable and transitional with the underlying Raging River Formation. In the exposures along the McDonald Point road the arkosic sedimentary rocks above the Durham-Kanaskat flint-clay bed are intercalated with the epiclastic volcanic rocks of the Tukwila Formation. The formations are conformable.

<u>Age and correlation</u>.--On the basis of plant fossils and leaf impressions Jack A. Wolfe (Vine, 1962a, p. 13) considered the middle part of the formation, below the lowermost tongue of the Tukwila Formation, to be middle(?) and late Eocene.

The writer regards the Tiger Mountain to be in part equivalent to the Guye Formation (see discussion of Guye Formation). He also regards the Tiger Mountain at least in part equivalent to the Kummer "series" of Evans (1912, p. 46-49), to the "Puget Group" of Willis (1898) at Carbonado, Pierce County, and the coal-bearing rocks near Morton and Ashford, Lewis and Pierce Counties (Culver, 1919; Fisher, 1957). These rocks are overlain by and intercalated with epiclastic andesitic rocks similar lithologically to the Tukwila and its probable equivalents, the Ohanapecosh Formation (Fiske, 1960; Fisher, 1957) and the Northcraft Formation (Snavely and others, 1958; Vine, 1962a, p. 6) (see discussion of Tukwila Formation).

Leaf impressions are present in the rocks exposed along the McDonald Point road but none was collected by the writer.

Tukwila Formation.

Distribution and thickness.--Epiclastic andesitic volcanic rocks overlie the Tiger Mountain Formation in the northwestern part of the map area (pl. 1). They are assigned herein to the Tukwila Formation. They occupy about the same stratigraphic position and are very similar lithologically to the Tukwila Formation in the Hobart quadrangle (Vine, 1962a, 1962b). Detailed mapping in the western part of the North Bend and northern part of the Cumberland (7½-min.) quadrangles may, however, indicate that the volcanic rocks are a part of a tongue of the Tukwila Formation in the upper part of the Tiger Mountain Formation.

The Tukwila Formation has a maximum exposed thickness of 700 feet in the map area. In the Hobart quadrangle the tongues of the lower part of the formation have thicknesses of 350 and 475 feet and the main body is 6,175 feet thick (Vine, 1962a, p. 18-19).

Lithology.--The outcrops of the Tukwila Formation are weathered and the rocks are poorly exposed. They consist of yellowish-gray to reddish-brown-weathering pumice tuff-breccia, lithic crystal tuff-breccia, lithic pumice lapilli-tuff, volcanic sandstone and fine- to coarse-grained crystal tuff. All are thick- to thin-bedded. Abundant large boulders of dark-gray fine-grained andesitic flow rock suggest that the formation may include some lava flows, although none were observed in outcrop.

Contact relations.--The base of the Tukwila Formation is conformable and gradational with the top of the Tiger Mountain Formation. The contact between the Tukwila Formation and the overlying Mount Catherine Tuff was not located in the field, but the writer considers it to be unconformable (see discussion of Mount Catherine Tuff).

Age and correlation.--On the basis of plant fossils and leaf impressions collected from the Tukwila Formation in the Hobart quadrangle, Jack A. Wolfe (Vine, 1962a, p. 14-16) considered the formation to be late Eocene.

Reconnaissance field mapping for the Northern Pacific Railway in the Morton area (see Fisher, 1957, pl. 1), in the Rainier Corridor of the Snoqualmie National Forest, Pierce and Lewis Counties (Hammond, 1960), in the Green River area (Wodzicki, 1960; Hammond and Rice, 1961), leads the writer to believe that the Ohanapecosh (Fiske, 1960; Waters, 1961), Tukwila and very likely the Northcraft (Snavely and others, 1958; Vine, 1962a, p. 6) Formations are correlatives. These formations are very similar lithologically; they consist predominantly of massive thick-bedded epiclastic andesitic volcanic rocks and dark-colored lava flows; they conformably overlie strata which have been assigned to the "Puget Group" and are intercalated and transitional with them. Tracing the contact between the Ohanapecosh Formation and the unconformably overlying Stevens Ridge Rhyodacite (Fiske, 1960; Waters, 1961) from the Mowich River in Mount Rainier National Park northward to the Green River, the writer found that the Ohanapecosh thins from a maximum exposed thickness of 15,000 feet along the Mowich Lake road to a minimum thickness of 700 feet in the map area. Further detailed field mapping between the Cowlitz and Snoqualmie Rivers along the Cascade foothills is necessary to substantiate these correlations.

Guye Formation.

Distribution and thickness.--Interstratified micaceous sandstone, shale, carbonaceous shale and chert conglomerates constitute the lowest stratigraphic unit exposed in the northeastern part of the map area (pl. 1). These rocks were originally grouped with chert, limestone and rhyolite by Smith and Calkins (1906) and designated as the Guye Formation. Foster (1960, p. 111-113) restricted the clastic sedimentary rocks to the Guye Formation, assigned the chert, limestone, and basalt to the Denny Formation, designated the rhyolite in the Guye Formation of Smith and Calkins as the Mount Catherine Rhyolite and extended the name

"Naches Formation" to the interstratified micaceous sedimentary and volcanic rocks overlying the Mount Catherine Rhyolite.

Well-rounded pebble-cobble conglomerate, containing abundant clasts of dark chert and quartzite and a few white silicified pumice in a matrix of arkosic, micaceous coarse-grained sandstone, is exposed along the southern slope of Mount Washington (G 1) north of the map area. This rock is very similar to the conglomerates present in the upper part of the Guye Formation along the Cascade crest (G 2) north of the map area. These rocks are considered tentatively as a part of the Guye Formation.

Foster (1960, p. 113) estimated the thickness of the formation to be about 5,000 feet. A minimum exposed thickness of 4,400 feet occurs along the line of the tunnel of the Chicago, Milwaukee, Saint Paul and Chicago Railroad along the east flank of the Mount Catherine anticline (G 3).

<u>Lithology</u>.--The formation includes light-gray, olive to brown lithic, arkosic to feldspathic micaceous fine- to very coarse-grained sandstone; gray to black micaceous shale; black carbonaceous shale and black to gray chert, quartzite and pumice granule-cobble conglomerate. The conglomerate is the most distinctive lithology and is present in large amounts in the upper part of the formation northeast of Mill Creek (G 4). The beds range in thickness from 6-50 feet and are interstratified with sandstone. The sandstone occurs in thin to thick beds; locally it is cross bedded. The shale is thin bedded to laminated. Black

fissile shale, almost like slate, is exposed along U.S. Highway 10 and Coal Creek (G 5). The rocks are gray and intensely indurated in the road cuts along U.S. Highway 10 northwest of the summit of Snoqualmie Pass.

Contact relations.--The base of the Guye Formation is not exposed in the map area. Danner (1957, p. 249-250) reported finding the Guye unconformably overlying ribbon chert and chert breccia of his Stillaguamish Group of Permian age between Snow Lake and Melakwa Pass, about 3 miles northwest of Snoqualmie Pass. A fault extends north-northeastward along the east side of the Snoqualmie River valley between the river and the Cascade crest north of the map area. Rocks of the upper part of the "Naches Formation" have been dropped along the west side of the fault and lie in juxtaposition with the rocks of the Guye Formation.

The Guye Formation is unconformably overlain by the Mount Catherine Tuff. The contact is exposed along the slope south of Rockdale Creek (MC 6) north of the map area (see discussion of Mount Catherine Tuff). The unequal distribution of the Guye Formation along the flanks of the Mount Catherine anticline with respect to the outcrop of the Mount Catherine Tuff suggests an unconformable relationship between the two formations. The Guye had been more deeply eroded, possibly as much as a few hundred feet, in the area along the west flank of the anticline before deposition of the overlying Mount Catherine. No conglomerate is exposed here below the Mount Catherine. Further evidence of the unconformity is the absence of overlying andesitic volcanic rocks which would be probably equivalent to the Tukwila Formation.

Age and correlation.--Foster (1960, p. 113) considered the Guye Formation to be Paleocene or Eocene. He collected leaf fossils from an outcrop along the southwestern side of Coal Creek (G 6) and submitted them to R. W. Brown of the U.S. Geological Survey for identification.

The writer considers the formation to be probably middle to late Eocene on stratigraphic evidence. The conglomerates along the south slope of Mount Washington occur stratigraphically at about the same position as the Tiger Mountain Formation. Proximity of these outcrops to the exposures of the Tiger Mountain suggest that the two formations may be correlatives. The writer also considers tentatively that the Guye Formation and the lower part of the Roslyn Formation (Bressler, 1951, p. 35-39) may be correlatives. The lower part of the Roslyn Formation is similar lithologically to the Guye Formation. Furthermore, epiclastic volcanic rocks similar to the Tukwila and Ohanapecosh Formations are exposed in a position stratigraphically above the Roslyn Formation along the Northern Pacific Railroad about 6 miles east of Cle Elum (G 7). Further field work in the area between the southeastern part of the map area and the Roslyn basin is necessary to establish this correlation.

Mount Catherine Tuff.

Definition and type section.--A distinctive lithologic unit consisting predominantly of rhyolitic to dacitic tuff is exposed in the northeastern part of the map area (pl. 1). This unit was originally mapped as rhyolite within the Guye Formation by Smith and Calkins (1906). Foster (1960, p. 114) separated the rhyolite and the overlying interstratified sedimentary rocks, basalt and rhyolite from the Guye Formation. He assigned the overlying rocks to the "Naches Formation," and he named the rhyolite unit the Mount Catherine Rhyolite for the mountain west of Mill Creek. He defined the unit as consisting of light-colored flows, tuff, tuff-breccia, most of which contained fine-grained quartz phenocrysts, and minor volcanic sediments. He designated the type section along Mill Creek. The creek flows through a very steep-walled canyon and the exposures of the Mount Catherine are stream-worn and weathered. A better exposed section of the unit occurs along the road at the west side of Lake Keechelus near the north end of the lake (MC 1). Here the unit consists only of rhyolitic to dacitic vitric and crystal-vitric tuff. No rhyolitic intrusions and lava flows, which Foster described at Mill Creek, are present here. The writer prefers to designate this locality as the type section and to redefine the unit as the Mount Catherine Tuff. It consists of rhyolitic to dacitic tuff, in which dacitic predominates, and a subordinate amount of volcanic sediments. The sediments are exposed in the cuts along U.S. Highway 10 east of Hyak (MC 2). Rhyolitic intrusions and lava flows are not considered a part of characterizing lithology because they occur abundantly in the overlying "Naches" and Enumclaw Formations. Also the intrusions are not a stratigraphic unit.

A detailed description of the type section and the contact relations of the formation are described below.

Distribution and thickness.--The tuff forms an arcuate outcrop belt around the nose of the southward-plunging Mount Catherine anticline (pl. 1). It is exposed in the core of the northwest-trending Keechelus Ridge anticline along Gold Creek and in the spur ridges of Kendall Peak north of the map area.

A maximum exposed thickness of 1,420 feet is present at the type section.

At least 1,400 feet of contact metamorphosed dacite pumice crystal-vitric tuff is present along the north slope of Mount Washington (MC 3) north of the northwestern corner of the map area.

Fuller (1925, p. 61) reported a thin "flow" (the quotes are the writer's) of "amygdaloidal" dacite forming one of the Keechelus "flows" above the pre-Tertiary basement on the western slope of Mount Washington. It is light buff in color, weathers dark brown and is composed of a felted mass of highly altered fine-grained laths of plagioclase and many small quartz grains. This dacite may be a part of the Mount Catherine Tuff.

The exact distribution of the tuff in the northwestern part of the map area is uncertain. Although float of similar tuff was observed in the area south of Palmer Junction on the Green River (MC 4), along the western side of the map area, no tuff could be found in place. The unexposed interval in which the unit is presumed to be present between volcanic rocks of the Tukwila Formation and massive lava and breccia flows of the overlying Enumclaw Formation is 210 feet thick south of the Green River and 540 feet thick along the McDonald Point road to the north. Dense vegetation, thick soil cover and sporatic veneer of glacial deposits conceal the bedrock in the area. Erosion may haae partly or entirely removed the tuff before it was buried by the flows of the Enumclaw Formation or the tuff accumulated to no great thickness in this area.

Petrography.--At the type section (MC 1) the Mount Catherine Tuff consists essentially of three tuff lithologies: a very fine-grained vitric tuff, a crystal-vitric tuff in which crystals of only quartz are present and a crystal-vitric tuff in which crystals of both quartz and feldspar are clearly discernible. The percentage of quartz and feldspar and their ratio ranges widely in this tuff. The crystal-vitric tuff is gradational into minor amounts of lithic-pumice-crystal-vitric tuff and tuff-breccia. No volcanic sediments of the type Foster (1960, p. 114) described from the road cut along U.S. Highway 10 east of

Hyak were noted in the exposures along the abandoned right-of-way.

The vitric tuff is medium bluish gray and stained with iron oxides (spec. 1). It is dense, has an extremely well-developed eutaxitic layering, and closely resembles a highly siliceous laminated fine-grained quartzite. The tuff is devitrified and recrystallized; the fragmental texture is almost completely obliterated. Microscopically it consists of a few scattered lenses, less than 2 mm in size, of coxcomb and granular quartz and sericite in a very fine-grained granoblastic groundmass of quarts and sericite. Granular magnetite and hematite dust accentuate the layering.

The quartz-bearing crystal-vitric tuff is also medium bluish gray and stained by iron oxides (spec. 2). It has a highly compressed vitroclastic texture in which the shards are squeezed between crystals and a few fine lithic fragments. The groundmass is partly devitrified; very fine-grained crystals have developed within a few shards to form a pectinate texture. A few veinlets of fine-grained quartz traverse the rock. The quartz crystals are corroded and constitute up to 10 percent of the rock. Patches of granular quartz, calcite, sericite, and granular magnetite, weathering to hematite, are scattered throughout the rock. Some clusters occur as pseudomorphs of prismatic grains which may be former feldspar.

The crystal-vitric tuff, containing easily discernible crystals of both quartz and plagioclase, is dusky blue to grayish blue (spec. 3). It contains about 10 percent crystals of corroded quartz and 25 percent plagioclase which are largely altered to calcite. The highly compressed vitroclastic groundmass is silicified. Magnetite, hematite, sericite and a very small amount of epidote are present.

The intense devitrification and silification is believed due mainly to hydrothermal alteration. At its eastern exposures, along U.S. Highway 10 east of Hyak and along the Chicago, Milwaukee, Saint Paul and Pacific Railroad (MC 5) the tuff is sheared and intruded by andesite. Additional structural features (see discussion of Structure) suggest that a fault trends the length of Lake Keechelus and is very likely the site of hydrothermal alteration.

Stratigraphic section.--The columnar section of Mount Catherine Tuff exposed at the type locality (MC 1) is listed in Appendix A. Three tuff units possibly can be distinguished in this section: a lower unit of about 720 feet of gray dense vitric tuff, a middle unit of about 330 feet of quartz plus feldspar -bearing crystal-vitric tuff and an upper unit of about 320 feet of only quartz-bearing crystal-vitric tuff. The top 50 feet of quartz and feldspar-bearing crystal-vitric tuff is perhaps part of a fourth tuff unit. The diverse tuff lithologies and the presence of volcanic sediments which occur above the base of the formation at its exposure along the northern side of U.S. Highway 10 east of Hyak suggest that the Mount Catherine Tuff is a composite ignimbrite. The intense silicification of the formation has probably obscured many of the textural features which would serve to distinguish the cooling units of the tuffs in the outcrop.

Contact relations.--The lower and upper contacts of the Mount Catherine Tuff are not exposed at the type locality (MC 1). However, the base is exposed in road cuts along the Bonneville Power Administration power line right-of-way south of Rockdale Creek and west of the Cascade crest (MC 6), just north of the map area. Here the basal rocks of the formation consist of a 16-foot interval of interstratified epiclastic thin-bedded gray tuff and lithic lapilli-tuff. They are overlain by about 30 feet of gray lithic tuff-breccia. The tuff rests along a sharp contact disconformably upon black well-indurated shale of the Guye Formation.

A sill of pink-weathering, very light-gray, highly silicified felsite porphyry, with abundant white coarse-grained feldspar crystals, has intruded the upper contact exposed along Mill Creek (MC 7). The platy-jointed upper 10 feet of the sill contains abundant black fine-grained sandstone fragments, ranging from ½-5 inches in size. The sill is overlain by 10 feet of dark-gray, iron oxide-stained, thin-bedded fine-grained sandstone at the base of the "Naches Formation." The base of the sill is in contact with similar felsite porphyry rock, suggesting the possibility of multiple intrusions along the contact at this locality.

Although the writer was unable to locate the contact he considers the Mount Catherine Tuff to overlie the Tukwila Formation unconformably.

Age and correlation.--The tracing of the distinctive lithologic unit which constitutes the Mount Catherine Tuff is paramount to the understanding of the stratigraphic and structural geology of the central Cascade Range. By the nature of its lithology and its thickness this unit should have wide areal extent. However, structural and intrusive complexities greatly hinder the attempt to trace the unit away from the type area. Similar lithologic units have been found not too distant from this area. Thick dacite crystal-vitric tuff overlies conglomerate identical to the conglomerate in the uppermost Guye Formation at Mount Washington, about 12 miles west of Mount Catherine. Fiske (1960) delineated a thick rhyodacite crystal-vitric tuff in Mount Rainier National Park and named it the Stevens Ridge Formation. The Stevens Ridge underlies lava and breccia flows, which he assigned to the Fifes Peak Formation, but the writer has traced these same flows northward to the White River into the Enumclaw Formation. Likewise, the underlying Stevens Ridge tuff has been traced northward to South Prairie Creek (MC 8) about 8 miles southwest of the map area. Here it has a minimum exposed thickness of 320 feet.

The Stevens Ridge has also been traced northeastward from The Dalles (Waters, 1961, p. 51) on U.S. Highway 410, in the southeastern part of the Greenwater quadrangle, to the Greenwater River where it is concealed by flows of the "Ellensburg Formation" (Waters, 1961, p. 50) which underlie the tableland at Naches Pass. The tuff possibly extends east of Pyramid Peak and forms the mass of white porphyritic rhyolite, the largest that Smith and Calkins (1906, p. 8) observed in the Keechelus. In addition the writer made a one-day reconnaissance into the Quartz Mountain area, south of Cle Elum (MC 9), to examine the base of the "Naches Formation" (Stout, 1959). There, a crystal-vitric tuff very similar to the tuff at Hyak, greater than 1,000 feet thick, rests upon amphibolite of pre-Tertiary age. Smith and Calkins (1906) included the same unit in their Kachess Rhyolite which they considered to underlie in part their Naches Formation.

On the basis of these relationships the writer tentatively correlates the Mount Catherine Tuff with the Stevens Ridge Rhyodacite. Additional field mapping is necessary to substantiate this correlation. Critical localities for re-checking are (1) the area east of the Rainier State School at Buckley along the south side of the White River, (2) the northern slope of Rattlesnake Mountain south of North Bend, and (3) the areas containing crystal-vitric tuffs west of Quartz Mountain, at Mount Clifty (Stout, 1959, p. 80), and from there southwestward to Naches Pass and northward to the Yakima River.

Wolfe (1961, p.228-229) identified fossil leaves from the lower part of the Enumclaw Formation (see discussion of that formation) as late Eocene to early Oligocene. The Mount Catherine Tuff, underlying the Enumclaw Formation, is considered to be the same age.

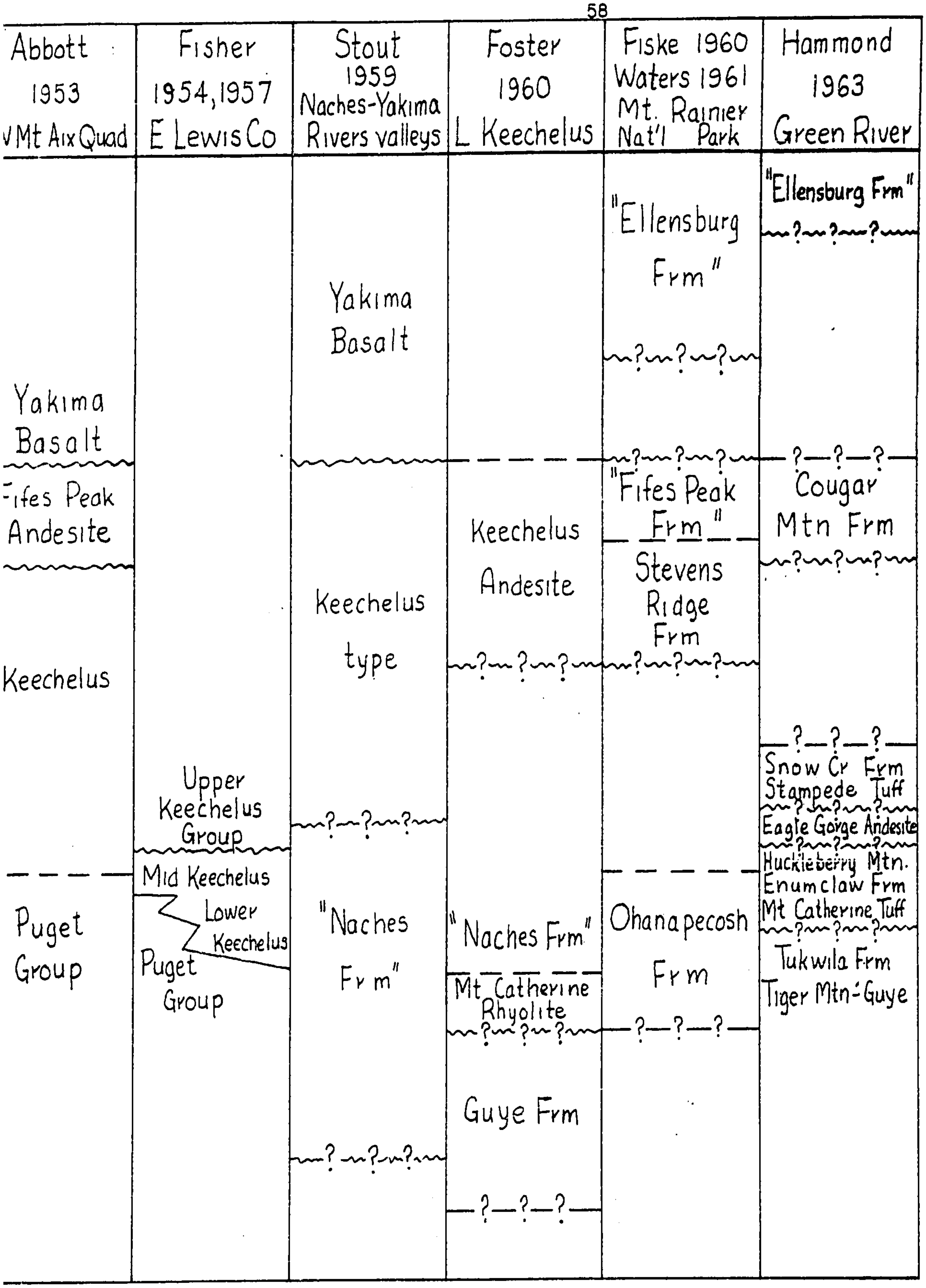
Keechelus Volcanic Group.

Previous work.--The contributions to the geology of the Keechelus rocks by previous workers are summarized below in their chronologic order. The geographic locations referred to are shown in plate 4. The various stratigraphic divisions of the Keechelus are shown in the comparative stratigraphic chart (pl. 12).

In the Snoqualmie Pass folio, Smith and Calkins (1906, p. 8-9) defined the Keechelus Andesitic Series as a voluminous assemblage of mainly andesitic volcanic material and a small amount of sedimentary rock. The series occupied most of the western half of the Snoqualmie Pass quadrangle (30-min.) and extended westward and southward into the adjacent Cedar Lake and Mount Aix quadrangles, respectively. They determined its thickness at 3,000 to 4,000 feet. The volcanic rocks include lava flows, agglomerates (tuff-breccias) and tuffs. The fragmental rocks are predominant but the proportion varies locally. They are predominant in the northern part of the quadrangle and about Stampede Pass but lava flows are most abundant to the south. Lithologically the rocks include

	Smith & Calkins 1906 Snoqualmie Pass Quad	Weaver 1916 King County	Warren 1941 Grant 1941 Mt Aix Quad	Warren & others 1945 King County	Abbott 1953 NW Mt Aix Quad	I E
Pliocene	Upper Keechelus					
Upper Miocene	Ellensburg; Lower Keechelus	Enumclaw series	Yakima Basalt			
Middle Miocene	Yakima Basalt	? ? ? granodiorite ? ? ?	? ? ? Fifes Peak Andesite = Upper Keechelus		Yakima Basalt	
Lower Miocene	Guye Frm				Fifes Peak Andesite	
Upper Oligocene	? ? ?		Oreodont-bearing beds = Lower Keechelus		Keechelus	
Middle Oligocene			? ? ?	Keechelus Andesitic Series		
Lower Oligocene		? ? ?				M
Upper Eocene	? ? ? Teanaway Basalt	Puget Group		Puget Group	Puget Group	P
Middle Eocene	? ? ? Naches Frm					
Lower Eocene	? ? ? Swauk Frm					
Paleocene	? ? ?					

Plate 12 Comparative stratigraphic chart showing various stratigraphic divisions of



ıic divisions of the Keechelus recognized by previous workers pyroxene andesite, dacite, rhyolite and basalt, the first two being most abundant. Smith and Calkins believed that the series overlay the Yakima Basalt and underlay the Ellensburg Formation, both then dated as Miocene, but included rocks of post-Miocene age as well. Consequently they were convinced that the Keechelus comprised volcanic rocks of two ages. They subdivided the Keechelus into two parts. The lower part was the most extensive; it included considerably altered rocks and, therefore, was considered as a distinct lithologic unit. It unconformably overlies their defined Swauk and Guye Formations and Teanaway Basalt. Their map also showed that the lower Keechelus rests unconformably upon their Naches Formation and Yakima Basalt. The upper Keechelus, consisting mainly of lava flows, is exposed in the drainage basins of the Greenwater and Naches Rivers. It is flat-lying in contrast to the lower part and is as fresh as lava flows of recent volcanism. Unfortunately they did not designate a type area; however, most geologists have fairly well agreed that Lake Keechelus is the type area and the rocks exposed there represent the predominating lithologies of Smith and Calkins' lower Keechelus.

Weaver (1916, p. 84, 232-235) gave the name "Enumclaw Series" to the sequence of volcanic rocks consisting predominantly of lava flows extending along the western foothills of the Cascade Range from Enumclaw northward to North Bend in King County, and considered them at least in part equivalent to the upper part of the Keechelus Andesitic Series.

Fuller (1925) extended the Keechelus westward to the western border of the Cedar Lake quadrangle and considered the lava flows at Cedar (Chester Morse) Lake to be equivalent in part to the Enumclaw Series and to the lower Keechelus. He used the theory of magmatic differentiation to explain the increasing acidity upwards in a stratigraphic sequence of volcanic rocks. The lava flows are predominantly of basic andesite so he believed they represented the basal part of the volcanic sequence. He also believed that the Keechelus volcanic rocks are the effusive equivalents of the Snoqualmie granodiorite which was deroofed during its emplacement. The pyroxene diorite plutons at Meadow Mountain and Silver Peak are thought to be the rocks formed during the vent phase and final stage of the emplacement.

Coombs (1935, 1936) extended the name "Keechelus Andesitic Series" to include the lithologically similar rocks in Mount Rainier National Park. These rocks overlie carbonaceous sedimentary rock which he assigned to the Puget Group. He recognized two parts to the Keechelus rocks: a lower unit of altered rocks, structurally deformed and deeply dissected, and an upper unit of fresh, well-bedded lava flows and pyroclastic rocks. He regarded the series as comprising at least two formations. The uncertainties in the determination of a Miocene age for the Guye Formation of Smith and Calkins led Coombs to infer that parts of the "Keechelus" were probably older than Miocene. He considered the youngest Keechelus to be Pliocene.

Warren (1936, 1941), having mapped in the northern and eastern parts of the Mount Aix quadrangle, restricted the "Keechelus Andesitic Series" to the volcanic rocks underlying the Yakima Basalt. He subdivided the "Keechelus" into a lower and upper part, and named (1941) the upper the "Fifes Peak Andesite." The lower part was not given formational status. This part consists predominantly of altered andesite and dacite pyroclastic rocks, in excess of 2,000 feet thick. It unconformably overlies continental arkosic sedimentary rocks exposed in the Bumping River area and is intruded by a granodiorite which he considered to be a satellite of the Snoqualmie batholith in the northwestern part of the Mount Aix quadrangle. The Fifes Peak Andesite consists of predominantly pyroclastic rocks and a lesser amount of lava flows. It is about 2,000 feet thick, has gentle dips and is less altered than the lower "Keechelus." It overlies unconformably the lower "Keechelus" and is in turn overlain unconformably by Yakima Basalt. Unfortunately he did not designate any type localities. He considered the lower "Keechelus" to be Oligocene and the Fifes Peak Andesite to be early to middle Miocene. Without visiting the Naches Pass locality of Smith and Calkins, he thought his divisions were equivalent to theirs. He did not redefine the fresher flows which Smith and Calkins found atop their Ellensburg Formation.

Goodspeed and Coombs (1937) described "replacement breccias" along the east shore of Lake Keechelus in the lower Keechelus (the present writer's Stampede Tuff) of Smith and Calkins. They attributed the formation of what they believed to be porphyroblasts in a clastic matrix to metasomatic emanations from an igneous source at depth, possibly the Snoqualmie batholith.

Verhoogen (1937) in describing the Mount St. Helens volcano, in Skamania County, 40 miles south-southwest of Mount Rainier National Park, noted volcanic rocks similar lithologically to the Keechelus Andesitic Series and overlying sandstones and mudstones similar to the Eocene rocks in the Puget Sound lowland. On the basis of their lithology and stratigraphic position, he assigned the volcanic rocks to the "Keechelus."

Felts (1939) delineated a 1,800-2,400-foot sequence of intercalated lava flows and tuffs at Silver Star Mountain in southwestern Skamania County, about 100 miles southwest of the Snoqualmie Pass quadrangle. He named the sequence the "Skamania Andesite Series." The lower part of the series is intruded by granodiorite. He reported that the sequence underlies the Eagle Creek Formation of Hodge (1938) of lower Miocene age. To the east in Washougal basin the Skamania is overlain unconformably by the Yakima Basalt. He considered that the Skamania is about early middle Miocene, and equivalent in part to the Keechelus Andesitic Series.

Goodspeed, Fuller and Coombs (1941) noted the presence of plagioclase crystals in coaly material within the lower Keechelus strata of Smith and Calkins in the southeastern corner of Mount

Rainier National Park. They attributed the formation of the crystals to low temperate metasomatism. These strata were subsequently mapped as Stevens Ridge Formation by Fiske (1960).

Grant (1941) reported finding fossil bones of Eporeodon, an oreodont of middle Oligocene to early Miocene age, in the pyroclastic rocks of Warren's lower "Keechelus," northeast of Tieton Lake in the southeastern part of the Mount Aix quadrangle. He noted that the volcanic rocks are lithologically similar to those in the John Day Formation of central Oregon.

Warren and others (1945) designated as the Keechelus Andesitic Series the thick sequence of intercalated basic andesite lava flows and tuffs overlying the strata of the Puget Group with a slight discordance in central King County. To the west they found the lava flows interstratified with marine and continental sedimentary rocks of middle Oligocene to early Miocene. These rocks unconformably overlie the Puget Group.

Abbott (1953) remapped the northern part of the Mount Aix quadrangle. He recognized Warren's division of the "Keechelus Andesitic Series," restricting "Keechelus" to the lower part and maintaining "Fifes Peak Andesite" for the upper. However, he located differently the contact between "Keechelus" and "Fifes Peak," placing it from 4 to 8 miles west. He described the base of the "Keechelus" as concordantly overlying arkosic sedimentary rocks, which he assigned to the Puget Group, in the area north of

Bumping Lake. He attempted to separate the "Keechelus" into four lithologic subdivisions, from bottom to top--the Cougar Creek andesite, the Morse Creek andesite, the Richmond breccia and Mount Aix andesite porphyry--but could not trace them areally on his map. The Fifes Peak Andesite was described as unconformably overlying the "Keechelus" and discordantly underlying the Yakima Basalt. Abbott relocated the basal contact of the Yakima Basalt, placing his contact up to 7 miles east of Warren's location in the area southeast of the Bumping River. He showed the "Fifes Peak" to extend northward into the Cedar Lake and Snoqualmie Pass quadrangles. Unfortunately he neither presented stratigraphic sections of his "Keechelus" and "Fifes Peak" nor accurately defined the base or top of the stratigraphic units in terms of lithology or geographic location. He considered the "Keechelus" to be mainly Oligocene, based primarily upon the oreodont find, but ranging from Eocene to Miocene. He placed the age of the "Fifes Peak Andesite" as probably early Miocene because it stratigraphically overlies definite Oligocene and underlies the Yakima Basalt of middle Miocene age.

Fisher (1954, 1957) mapped a succession of interstratified epiclastic volcanic rocks and continental arkosic, coal-bearing sedimentary rocks in eastern Lewis and Pierce Counties, southwest of Mount Rainier National Park. He designated the sedimentary rocks as part of the Puget Group and the volcanic rocks as part of the lower "Keechelus Group." Together they constitute a stratigraphic thickness of about 8,750 feet. They are in turn overlain conformably by at least 5,700 feet of predominantly epiclastic volcanic rocks which he assigned to the middle "Keechelus Group." About 5,000 feet of tuffs and lava flows disconformably overlie the strata of the middle group and comprise the upper "Keechelus Group." On the basis of leaf fossils which were sent to R. W. Brown of the U.S. Geological Survey for identification, Fisher believed the Keechelus rocks ranged from middle(?) Eocene to Oligocene(?). More recently, Fisher (1961) advised against assigning formational names to the strata he mapped until more detailed work was completed north of his map area.

Stout (1959) remapped the southwestern part of the Mount Stuart and the southeastern part of the Snoqualmie Pass quadrangles. He redefined the "Naches Formation" to include the Manastash Formation of Smith (1904), part of the Keechelus Andesitic Series, Teanaway Basalt, Kachess Rhyolite and Yakima Basalt of Smith and Calkins (1906). The formation has a minimum thickness of 8,000 feet and nonconformably overlies crystalline rocks of pre-Tertiary age. It also lies in fault contact with the crystalline rocks. It is overlain unconformably by at least 1,000 feet of volcanic rocks which he designated as "undifferentiated rocks of Keechelus type." However, he stated that it was difficult to separate the two units in the field because of their similar volcanic lithologies. He included the Taneum Andesite (Smith, 1904) within

Keechelus type. He described the "Keechelus" rocks as resting unconformably on both earlier Tertiary and pre-Tertiary rocks and in turn overlain unconformably by Yakima Basalt. On the basis of identification of leaf fossils he considered the "Naches" at least in part Eocene and possibly extending into the Oligocene. No fossil leaves were found in the "Keechelus type" so he was able only to estimate its age as post-"Naches" and at least pre-middle Miocene.

Foster (1960) remapped a large part of the Snoqualmie Pass quadrangle. He split the lower Keechelus of Smith and Calkins and assigned it to his redefined "Naches Formation." He renamed the upper part the "Keechelus Andesite" and proposed as its type section the more than 3,500 feet of strata exposed on the west face of Rampart Ridge, 2 miles northeast of Lake Keechelus. He neither described the rocks in any detail nor clearly defined the stratigraphic relationships except to report that the "Keechelus" unconformably overlies the Guye Formation in the area north of Snoqualmie Pass and the "Naches Formation" east of Lake Keechelus. He considered the age to be late Oligocene or lower Miocene, based on the oreodont find of Grant in the Mount Aix quadrangle.

Fiske (1960) remapped the "Keechelus Andesitic Series" of Coombs in Mount Rainier National Park. He divided the rocks into the Ohanapecosh Formation, the Stevens Ridge Formation, and the "Fifes Peak Formation." The Ohanapecosh is defined as consisting in excess of 10,000 feet of interstratified mainly andesitic epiclastic volcanic rocks and lava flows. He placed the age of this formation as late Eocene, on the basis of leaf fossils identified by R. W. Brown of the U.S. Geological Survey. These rocks are essentially the same as the lower and middle "Keechelus Group" of Fisher. The Ohanapecosh is overlain unconformably by 500-3,000 feet of rhyodacite tuffs and minor volcanic sedimentary rocks of the Stevens Ridge Formation. He correlated the Stevens Ridge with the tuffs below the base of Warren's Fifes Peak Andesite and, therefore, thought the Stevens Ridge is stratigraphically equivalent to the beds in which Grant found the oreodont bones. He considered the age of the formation to be late Oligocene to early Miocene. The Stevens Ridge is in turn overlain conformably by at least 2,400 feet of lava flows and minor epiclastic rocks. He thought these rocks were equivalent to the Fifes Peak Andesite. Because he restricted his formation to the strata above the light-colored tuffs which Warren had included in the base of his unit, Fiske named his strata the "Fifes Peak Formation." The age of this formation is placed as probably early Miocene. He added that the Fifes Peak extends northward into the Cedar Lake quadrangle where the thickness probably exceeds 5,000 feet.

Crandell and Gard (1960) assigned the name "Keechelus Andesitic Series" to at least 2,500 feet of andesitic epiclastic volcanic rocks conformably overlying strata of the Puget Group in the northeastern corner of the Buckley (7½-min.) quadrangle, lying west of the Cedar Lake quadrangle. Leaf fossils obtained from the strata enabled them to date the rocks as middle to late Eocene.

Wolfe (1961), on the basis of leaf fossils collected from several localities of "Keechelus" and Puget rocks, concluded that the uppermost Puget Group east of Seattle is correlative with the lowermost part of the "Keechelus" east of Tacoma. Furthermore, the fossils indicated that the "Keechelus" is as old as late Eocene to early Oligocene and as young as late Oligocene to early Miocene.

The comparative stratigraphic chart (pl. 13), showing the various divisions of the Keechelus as designated by some of the above workers, reveals (1) the broad time range, from late Eocene to Pliocene, in which Keechelus rocks have been dated, (2) the tendency for each worker to date the Keechelus as older than previously dated, (3) the lack of stratigraphic correlation among the workers, and (4) the confusion among the workers as to what constitutes the Keechelus of Smith and Calkins.

Waters (1961) aptly indicated the confusion in the interpretations of the previous workers. He emphasized that the earlier workers, without visiting the Naches Pass locality of the upper Keechelus of Smith and Calkins, had extended and redefined the series so that now the name Keechelus has become a wastebasket of Tertiary volcanic rocks in central Washington. Consequently he visited Naches Pass and recognized there that the fresh flows of

Smith and Calkins were a part of what he believed to be the "Ellensburg Formation." Furthermore, he interpreted that these flows rest upon beds lithologically similar and stratigraphically equal to Fiske's "Fifes Peak Formation." To the east, at Ravens Roost and along Crow Creek, Waters found Ellensburg resting upon Yakima Basalt and lapping westward upon rocks very similar to Warren's Fifes Peak Andesite. Having uncovered these relationships, Waters concluded that Warren's Fifes Peak Andesite is equivalent to the lower Keechelus of Smith and Calkins, not to their upper Keechelus. In addition, he believed that Fiske's Stevens Ridge and "Fifes Peak" Formations underlie the southern third of the Snoqualmie Pass quadrangle. He extended his reconnaissance northward from Naches Pass. In the Green River valley in the map area (pl. 1) he found "Stevens Ridge" (the present writer's Stampede Tuff) resting unconformably upon what he thought was the Ohanapecosh Formation of Fiske. At Stampede Pass and along the east shore of Lake Keechelus he found similar relationships and lithologies. Therefore, he reasoned that Smith and Calkins had included parts of these formations--Ohanapecosh and Stevens Ridge--in their lower Keechelus. In conclusion, Waters proposed abandoning the name Keechelus Andesitic Series in favor of what he thought are the better defined Stevens Ridge, "Fifes Peak" and Ellensburg Formations.

The present writer favors retaining the name Keechelus until the stratigraphy of these rocks in the Snoqualmie Pass quadrangle is established. Furthermore, it must be determined if the more recently designated formations actually comprise the Keechelus in the quadrangle and are reliable stratigraphic units. The alternative to Waters' proposal is to go into the Lake Keechelus area, establish the stratigraphy there, and trace the units outwards.

The Geologic Names Committee of the U.S. Geological Survey (George Cohee, letter dated February 12, 1963) approved abandoning the name Keechelus Andesitic Series.

Martin L. Stout (letter dated April 26, 1963) has suggested including only the Eagle Gorge Andesite, Stampede Tuff and Snow Creek Formation in the Keechelus Volcanic Group.

Definition.--The Keechelus Andesitic Series of Smith and Calkins (1906) is redefined herein as the Keechelus Volcanic Group. It is a thick complex succession of volcanic rocks covering an area of about 750 square miles in the central Cascade Range, Washington. The rocks range in composition from basalt to rhyolite, with pyroxene andesite predominating. In their order of decreasing abundance, the rock types are tuff-breccias, lava flows and breccia flows, volcanic sediments and tuffs, including ignimbrites. The group comprises three sequences bounded by unconformities, shown in plates 11 and 13. Not all the sequences are preserved in any one local area. The sequences are divided into one or more formations on the basis of their lithology. These formations are originally defined and named in this report. The lowest sequence consists of the Enumclaw Formation and the overlying Huckleberry

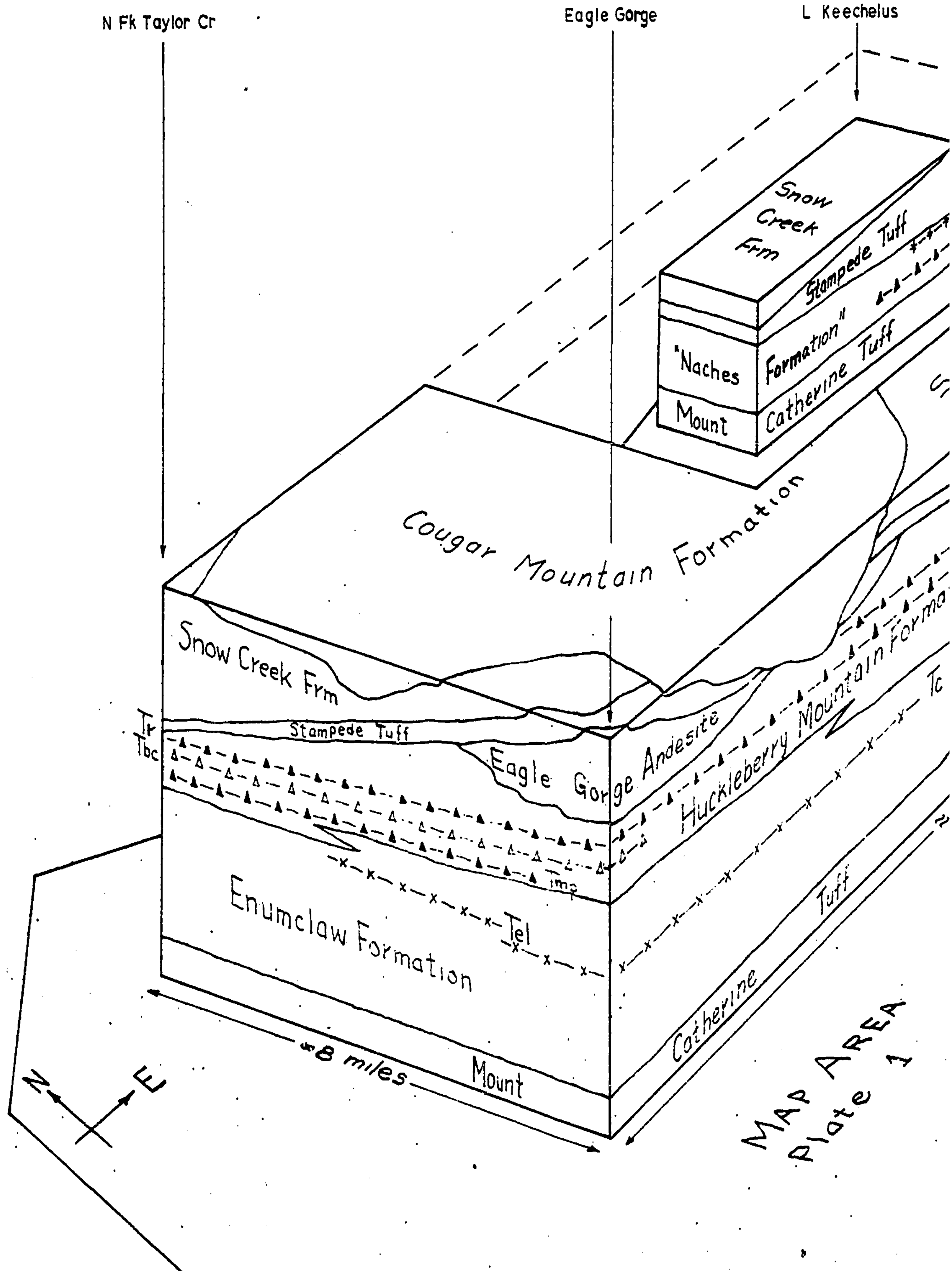
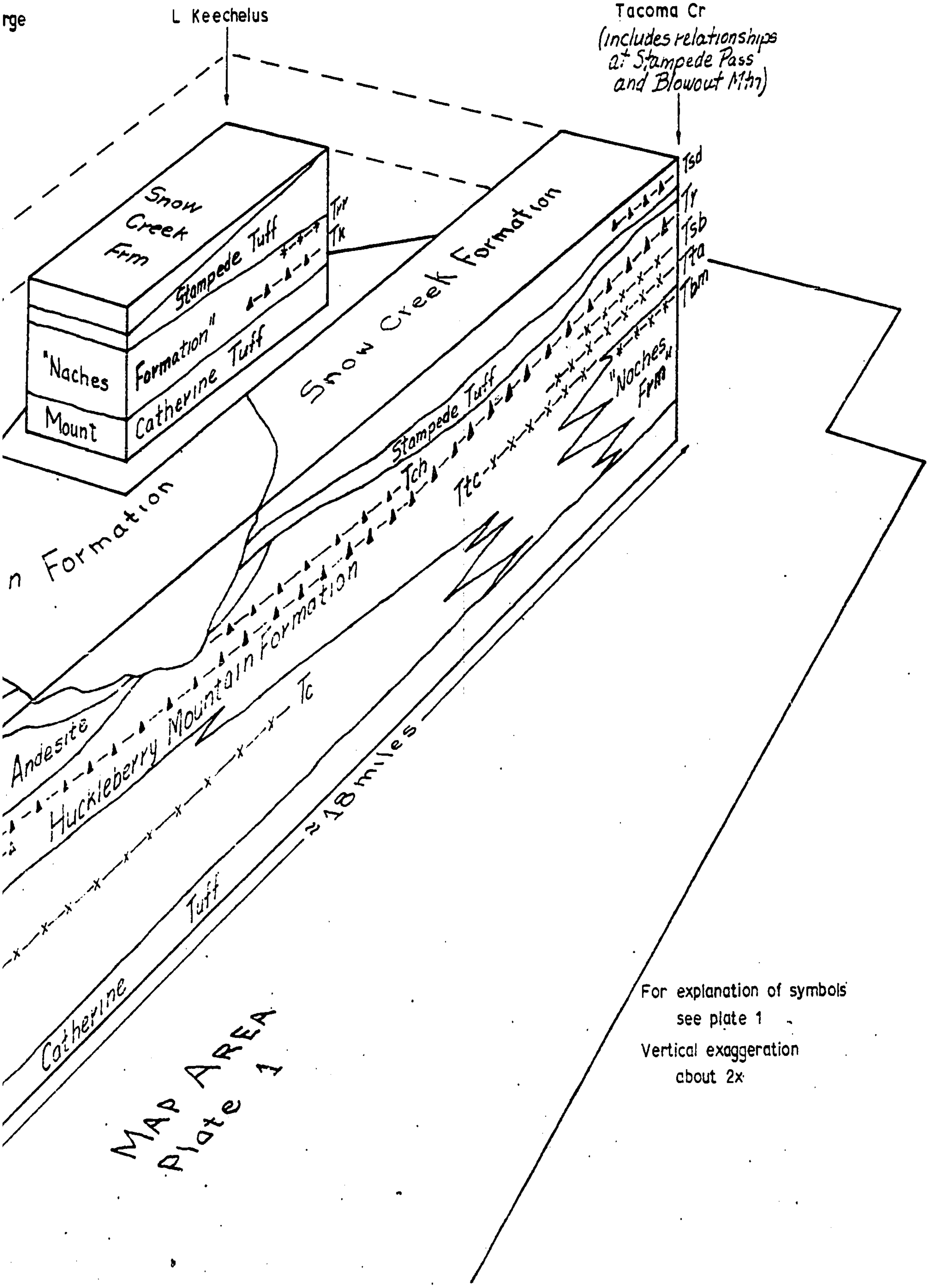


Plate 13 Diagram showing stratigraphic relationships of units of th



hic relationships of units of the Keechelus Volcanic Group

Mountain Formation. The Eagle Gorge Andesite composes the middle sequence. The upper sequence consists of the Stampede Tuff and overlying Snow Creek Formation. All these formations and their field-delineated correlatives, except the Eagle Gorge Andesite, are exposed in the Snoqualmie Pass quadrangle proximate to Lake Keechelus. These strata are undoubtedly the rocks that Smith and Calkins had in mind when they named them Keechelus.

The formations in the Keechelus Volcanic Group and their subunits (pls. 11 and 13) are discussed in the order of superposition in the descriptions which follow. The relationships of the formations are described here in order to better inform the reader of the regional stratigraphy.

The Enumclaw Formation conformably overlies the Mount Catherine Tuff and its correlative, the Stevens Ridge Formation, along the west slope of the Cascade Range. The formation consists mainly of lava and breccia flows which grade eastward near the Cascade crest into epiclastic volcanic rocks assigned to the Huckleberry Mountain Formation. These rocks in turn grade further eastward into the interstratified arkosic, micaceous coal-bearing sedimentary and volcanic rocks of the "Naches Formation" of Stout (1959) and Foster (1960). The "Naches Formation" conformably overlies the Mount Catherine Tuff in the Snoqualmie Pass quadrangle. The present writer prefers to retain quotes about the "Naches Formation" until a future time when it is ascertained that this formation is the same section of rocks which Smith and Calkins designated as Naches. The Enumclaw Formation extends southward from the map area into Mount Rainier National Park. The 2,400 feet of "Fifes Peak Formation" of Fiske (1960) is included in the lower part of the Enumclaw Formation. By reconnaissance mapping in the Greenwater (15-min.) and southern part of the Snoqualmie Pass quadrangles, the writer determined that the Fifes Peak Andesite of Warren (1941) does not extend a great distance west of the Cascade crest in the Snoqualmie Pass quadrangle. The yellowish-gray-colored tuff at the base of the Fifes Peak Andesite extends westward from Fifes Peak to the crest at a point about midway south of Arch Rock and the southern boundary of the quadrangle. From there it extends northward to Arch Rock where Smith and Calkins (1906, p. 8) and Waters (1961, p. 50-51) observed it. It rests upon interstratified lava and breccia flows and subordinate epiclastic rocks which are probably a part of Fiske's (1960) Sarvent and Crystal Mountain lava complexes of the Ohanapecosh Formation. From here the tuff trends eastward and northeastward into the drainage basin of the Naches River. The writer located outcrops of tuff of identical lithology along the American, Bumping and Tieton Rivers in the Mount Aix quadrangle, and, therefore, believes that this unit is traceable from Arch Rock southward to near the Tieton River where it rests upon the oreodont-bone-bearing beds of Grant (1941). The writer also believes that the fossil beds, the yellowish-gray tuff and the overlying Fifes Peak Andesite are considerably younger than the designated "Fifes Peak Formation" in Mount Rainier National Park and the Keechelus Volcanic Group in the Cedar Lake and Snoqualmie Pass quadrangles. The Enumclaw Formation extends southwestward from Mount Rainier National Park and constitutes the upper "Keechelus Group" of Fisher (1957).

The Huckleberry Mountain Formation conformably overlies the Enumclaw and Naches Formations. Along the Green River within the map area, the Eagle Gorge Andesite unconformably overlies the Huckleberry Mountain Formation. The Stampede Tuff, forming the base of the upper sequence in the Keechelus Volcanic Group, unconformably overlies the Huckleberry Mountain, Naches and Eagle Gorge Formations. This unit is the dacite tuff and tuff-breccia that Smith and Calkins observed along the Northern Pacific Railroad, along the east shore of Lake Keechelus and on the peaks to the west of the lake. The uppermost formation of the group is the Snow Creek Formation which conformably overlies the Stampede Tuff.

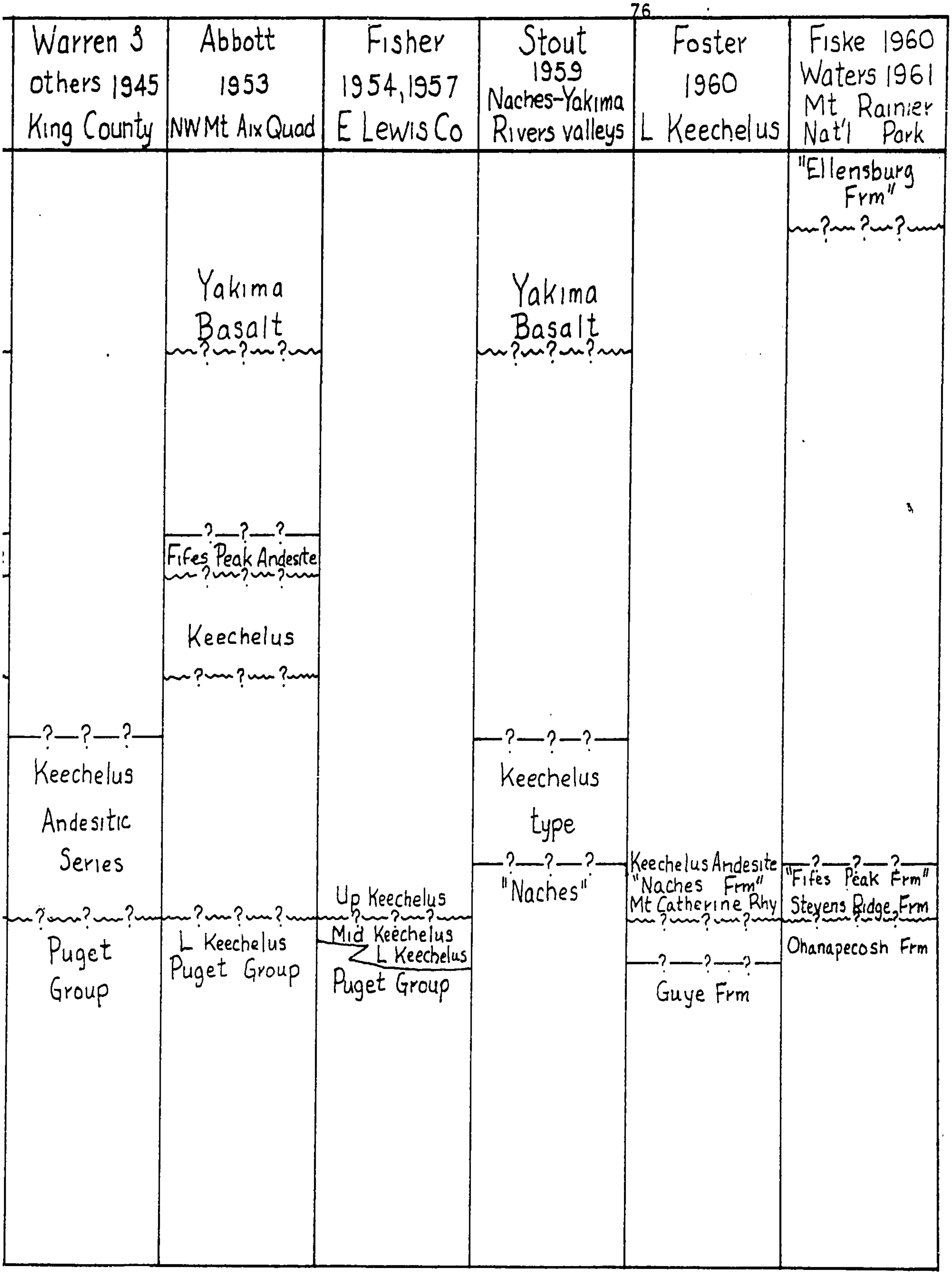
West of the Cascade crest the Keechelus Volcanic Group is overlain unconformably by the Cougar Mountain Formation, also newly described and named in this report. The unit extends eastward just to the western boundary of the Snoqualmie Pass quadrangle and was, therefore, probably not included by Smith and Calkins in their Keechelus series, This formation is considered to be younger than the Fifes Peak Andesite, because (1) it lies at a high structural and stratigraphic position, (2) the lithology is unlike Fifes Peak which is very similar to the Keechelus, and (3) the boulder conglomerates which are a major part of the Cougar

Mountain are suggestive of accelerated uplife and increased tectonic activity prior to the time of emplacement of the Snoqualmie batholith. Along the western Cascade foothills, west of the map area (pl. 1), the Keechelus Volcanic Group is overlain by sporadic remnants of Miocene continental sediments (Mullineaux, Gard and Crandell, 1959; Gard, 1960) and Pleistocene glacial deposits. A very small remnant of the Miocene sediments occurs in the south-central part of the map area. From Pyramid Creek to Naches Pass, in the southeastern corner of the map area, strata of the Huckleberry Mountain, Stevens Ridge, and probable Ohanapecosh Formations are overlain unconformably by the Naches Pass tableland flows of Smith and Calkins' upper Keechelus and Waters' (1961) "Ellensburg Formation." The writer prefers to enclose this name in quotes until the stratigraphy of the Ellensburg-like lithology is delineated in this part of the Cascade Range. Only Pleistocene glacial sediments and alluvium overlie the Keechelus Group in the eastern part of the map area (pl. 1).

The regional stratigraphic relationships discussed above are incorporated in the stratigraphic correlation chart (pl. 14), which is the writer's interpretation, based upon the lithologies, stratigraphic and structural positions of the units.

	Hammond 1963 Green River	Smith & Calkins 1906 Snoqualmie Pass Quad	Weaver 1916 King County	Warren 1941 Grant 1941 Mt Aix Quad	Warren & others 1945 King County
Pliocene	"Ellensburg Frm"	"Ellensburg Frm" =Up. Keechelus			
Upper Miocene		Yakima Basalt		Yakima Basalt	
Middle Miocene					
Lower Miocene	Cougar Mtn Frm			Fifes Peak Andesite	
Upper Oligocene				Oreodont-bearing beds	
Middle Oligocene					
Lower Oligocene	Snow Cr Frm Stampede Tuff Eagle Gorge Andesite Huckleberry Mtn	Lower Keechelus			Keechelus Andesitic Series
Upper Eocene	Enumclaw Frm Mt Catherine Tuff Tukwila Frm	Naches Frm	Enumclaw series Puget Group	L Keechelus Arkoses =? Puget Group	Puget Group
Middle Eocene	Tiger Mtn-Guye				
Lower Eocene					
Paleocene					

Plate 14 Stratigraphic correlation chart, showing writer's interpretation of stratigraphi
to Keechelus-Andesitic Series



n of stratigraphic relationships of Tertiary volcanic units which have been assigned

Enumclaw Formation.

Definition and type section.--An extensive section consisting of lava and breccia flows and subordinate interbedded tuff-breccia, volcanic sediment and tuff overlies the Mount Catherine Tuff on the western slope of the Cascade Range. This unit is redefined herein as the Enumclaw Formation. This formation constitutes essentially the same rocks that Weaver (1916, p. 84, 232-235) described as his Enumclaw Series.

The type section of the Enumclaw Formation is designated as the western slopes of Enumclaw Mountain and Boise Ridge (E 1) west of the map area. Here over 9,000 feet of strata, dipping about 20-45° S, are present. The lower part of the formation underlies Enumclaw Mountain. The middle part of the formation, consisting of epiclastic volcanic rocks, occurs in the saddle between the two ridges. The upper part of the formation underlies Boise Ridge. The rocks are generally not well exposed in this area; brush and second growth timber obscures the outcrops. The best exposures occur in road cuts along the southwestern slope of Boise Ridge. The stratigraphic section measured here is shown in Appendix A. Exposures of the middle part of the section occur along a road on the northwestern slope of Boise Ridge. The road was impassable in 1962 and a section was not measured.

Two members are recognized in the formation. They are the Cyclone Creek Flow and the Eagle Lake Flow. The Cyclone Creek

Flow Member is exposed near the top of the type section (Appendix A). The Eagle Lake Flow Member could not be traced into Boise Ridge. The members are described in the discussion of stratigraphic sections.

The formation conformably overlies the Mount Catherine Tuff and underlies conformably the Huckleberry Mountain Formation. The contacts with these formations are not exposed at the type section. The strata can be traced in the field and on aerial photographs to the north and east. The contacts have been examined in other areas and are described in the discussion of contact relations.

Distribution and thickness.--The areal extent of the formation is confined to the western slope of the Cascade Range. Within the map area (pl. 1) it occurs along the western side from Chester Morse Lake southward beyond the White River. The resistance to erosion of the flows is largely the reason for the abrupt high front of the west-central Cascades overlooking the Puget Sound lowland.

The flows have been traced from Greenwater eastward about 3 miles. Here they are interstratified and transitional with the epiclastic volcanic rocks which grade eastward and upward into the Huckleberry Mountain Formation. The bold outcrops of the flows do not persist to the east and the stratification is obscured by extensive forest cover.

The formation has been traced southward from the White River into Mount Rainier National Park where it includes at its base the 2,400 feet of lava flows and mudflows and minor amounts of tuffaceous clastic rocks which Fiske (1960) assigned to the "Fifes Peak Formation."

Excellent although discontinuous exposures of the formation occur along U.S. Highway 410, along the White River between the White River mill, west of the map area, eastward to Greenwater; along the road and railroad along the south side of the Green River west of the Howard A. Hanson dam, and along the Cedar River between Cedar Falls and the Chester Morse dam (E 2).

The formation ranges in thickness from about 3,600 to 9,600 feet. It is about 3,600 feet thick, measured along the axis of the West Twin Creek anticline from the top of the Stevens Ridge Formation at The Dalles along U.S. Highway 410, about 8 miles south-southeast of Greenwater, to West Twin Creek, taking into account the approximate stratigraphic displacement along the Twin Creek fault. The formation has a thickness of about 8,300 feet along the McDonald Point road, north of the Green River, and has a maximum exposed thickness of 9,600 feet along the road and railroad along the southern side of the Green River (see section in Appendix A). Fuller (1925, p. 59) estimated the base of his Keechelus Andesitic Series, which is essentially the same as the Enumclaw Formation, to be 8,000 feet between Ragnar (Cedar) Hill (E 3) just north of the map area, and the west side of Fish Creek

(E 4). The formation thins considerably to the east. The thinning is diagrammatically shown in plate 13.

Stratigraphic sections.--The stratigraphic section along the southwestern slope of Boise Ridge (E 1) and the southern side of the Green River are shown in Appendix A.

Two members in the formation are shown on the map for distances as far as they were traced. They are the Cyclone Creek Flow and the Eagle Lake Flow Members. They occur in the upper part of the formation. Their stratigraphic relation and areal extent are diagrammatically shown in plate 13. Their recognition and tracing proved to be most helpful in delineating the structural relationships in the area between Cyclone and Clay Creeks (E 5) and between Boundary Creek and Eagle Lake (E 6). They probably occur in the upper 4,610 feet of unexposed interval in the section studied along the south side of the Green River and were, therefore, not recognized here.

A considerable thickness of primarily epiclastic volcanic rocks underlies a prominent section of lava flows in the upper part of the formation. The lava flows are exposed at the Palisade, which is located along the west side of the West Fork of the White River (E 13) about 4 miles south of Greenwater. The flows are easily traceable northeastward to the floodplain of the White River. A 500-foot thick unit of very pale orange to dusky yellow fine tuff, very well sorted and probably of lacustrine origin, lies directly below the flows. The tuff is well exposed in the logging road cuts south of the West Fork (E 14) and has been traced eastward across the White River valley to the exposures along the U.S. Forest Service Greenwater River road (E 15). Epiclastic volcanic rocks and subordinate interbeds of thin flow units are exposed below this tuff along the road on Huckleberry Ridge. These relationships suggest that the flows in the upper part of the formation extend northward and eastward possibly as a tongue. A thin sequence, less than 300 feet thick, of epiclastic volcanic rocks has been observed in the middle part of the formation along Coal Creek (E 16), along the southern side of the Green River (E 17), and in the saddle between Enumclaw Mountain and Boise Ridge (E 18), west of the map area. These exposures occurring at about the same stratigraphic horizon indicate that a thin continuous unit of epiclastics occurs in the middle part of the formation.

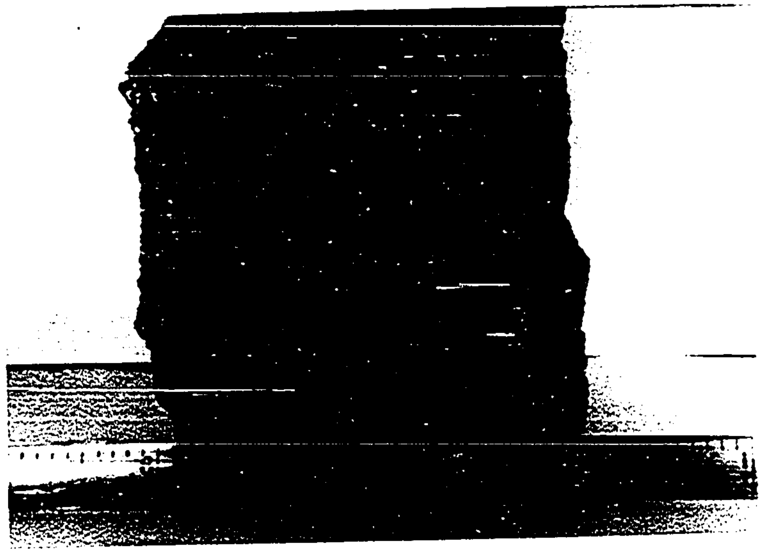
Cyclone Creek Flow Member.--The Cyclone Creek Flow Member consists of a hypersthene andesite porphyry flow (spec. 4; see pl. 15A). The rock consists of about 25 percent fine- to coarse-grained equant hypersthene phenocrysts in a very fine-grained holocrystalline groundmass. The plagioclase phenocrysts are about the largest observed in the flow rocks of the Keechelus; they have oscillatory and some patchy zoning and have a composition of An_{56-65}. The hypersthene has a very fine overgrowth of augite. The phenocrysts lie in an intergranular to

PLATE 15

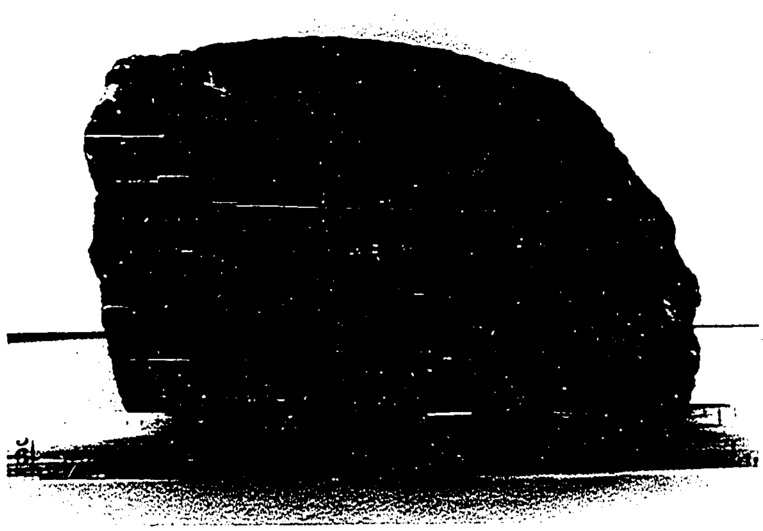
Lava flow rock types of the Enumclaw Formation

A. Pyroxene andesite porphyry flow rock from the Cyclone Creek Flow Member, exposed in quarry along Grass Mountain road in the SW¼NW¼NW¼ sec. 31, T. 20 N., R. 8 E. (spec. 4). Note varied size coarse-grained stubby prismatic crystals of plagioclase. Specimen shows veinlet of deuteric alteration.

B. Typical pyroxene andesite porphyry flow rock of the Enumclaw Formation. This is also the common rock type of the flows in the Keechelus Volcanic Group. Few prismatic crystals are plagioclase; finer dark crystals are pyroxene. Specimen is from the upper part of the formation exposed along road near East Twin Creek in the NE¼NW¼NE¼ sec. 1, T. 19 N., R. 8 E. Compare with flow rock of Cougar Mountain Formation (pl. 20B).



A



B

PLATE 15

pilotaxitic groundmass of plagioclase laths and granular pyroxene and magnetite. The flow lies about 800 feet below the top of the formation at the divide between Coal and Bear Creeks (E 7). It is best exposed in the quarry (E 8) along the road south of Grass Mountain, along the edge of the map. Here it has a minimum exposed thickness of 75 feet. At the base of the quarry face a 10-foot zone of well-developed coarse platy jointing is exposed. The platy jointing zone grades upwards through a 5-foot transition zone, which has extremely well-developed flow-layering, into a 10-foot zone of columnar jointing with the columns 2-3 feet in diameter. The columnar jointing zone extends for an additional 60 feet above the exposure in the quarry face. This exposure is probably of the lower part of the flow, which may be as much as 150 feet thick. Very similar flow rock is exposed atop Radio Hill (E 9) and at the south end of Boise Ridge (E 1). This flow overlies an extensive and thick section of altered breccia flows, which are exposed along Cyclone Creek (E 10) within the map area, and exposed east of First Lake (E 11) and along the southwestern face of Boise Ridge (E 1), west of the map area. The Cyclone Creek Flow Member has a linear extent of 6 miles along a north-south direction and 6½ miles east-west.

Eagle Lake Flow Member.--The Eagle Lake Flow Member consists of porphyritic pyroxene andesite flow (spec. 5). The flow extends from the south side of Eagle Lake to the east side of Boundary Creek (E 12). Along the divide between Piling

Creek and Eagle Lake erosional remnants of the flow occur as huge blocks capping the ridge. The flow is discontinuous within the drainage basin of Boundary Creek. On the east side of the creek it underlies the McDonald Point Tuff and, therefore, forms the top of Enumclaw Formation here. The flow has a maximum exposed thickness of 650 feet at Eagle Lake and is traceable for about 2½ miles.

The flow rock appears as rubble in the outcrop but consists of very tightly fitting rounded blocks 4-12 inches in diameter. The flow rock is grayish black and weathers to a brownish gray. It contains about 5 percent phenocrysts in a pilotaxitic groundmass of plagioclase microlites and granular pyroxene and magnetite. The phenocrysts are up to 2 mm in size and consist of about 4 per cent plagioclase and one percent pyroxene. The plagioclase phenocrysts are lath-like to prismatic in habit and have a composition of An_{45-67}. The pyroxenes are equant to slender prisms and consist of both hypersthene and augite; the latter is subordinate.

Petrography.--The lava flows of the Enumclaw Formation consist predominantly of pyroxene andesite porphyry. A few minor flows of basalt are scattered throughout the formation. Light-colored flow-layered spherulitic and perlitic silicic flows occur in the middle part of the formation and are present south of the map area and north of the Clearwater River (Huntting, 1949, p. 42-53).

The pyroxene andesite porphyry flow rock (spec. 6) is grayish black to medium bluish gray to dark greenish gray in color (pl. 15B). It alters to a light brownish gray, a grayish red purple, or a pale blue. It is fine-grained to cryptocrystalline. The rock contains up to 35 percent phenocrysts, of which about 30 percent may be plagioclase and 5 percent augite. The plagioclase occurs as stubby prismatic crystals. The crystals are subhedral to euhedral, range up to 7 mm in size but average ½ mm, have patchy and oscillatory zoning, and contain a few inclusions of granular augite. The augite is commonly smaller in grain size, is anhedral and altered to chlorite, a yellowish-green unidentified mineraloid and granular magnetite. The groundmass is pilotaxitic to intergranular. The latter consists of plagioclase laths and granular augite and magnetite. Augite comprises as much as 25 percent and magnetite 5 percent of the groundmass.

The basalt flow rock (spec. 7) is generally medium gray to grayish black in color and shows a very fine-grained intergranular texture in which the minerals are similar to those in the pyroxene andesite porphyry flows. No olivine was detected in these rocks although the yellowish green mineraloid may be an alteration product of it.

The silicic flows are best exposed along the Weyerhaeuser Company logging roads east of the Clearwater River. They are moderate pink to light bluish gray in color and show extremely well-developed flow layering which is locally highly contorted and brecciated. Spherulites are abundant and can be observed in the outcrop.to have developed across the flow layering. The rock is very fine-grained. Analyses of the perlites (Huntting, 1949, p. 48) indicate that the rocks approximate rhyodacites to dacites in composition. They contain about 10 percent phenocrysts of plagioclase and a few hypersthene.

The breccia flows are more extensively altered than the lava flows. Plagioclase is replaced by calcite and a little chlorite. Pyroxenes are replaced by calcite, chlorite, and green to brown unidentified mineraloids. Zeolites are common in the matrix. They have been identified in hand specimens by their fibrous to bladed habit, degree of hardness and lack of reaction with dilute hydrochloric acid. Petrographically they form small clusters of radial fibrolamellae with rims of brown to green mineraloids. The individual zeolite minerals have not been identified. The altered flow rocks contain abundant very fine-grained low relief and low birefringent minerals which are probably clays.

The lithic fragments in air-fall tuff-breccia near Cyclone Creek (pl. 8) consist of both light-gray perlite and typical darker colored pyroxene andesite porphyry.

<u>Contact relations</u>.--The Enumclaw Formation is overlain conformably by the Mount Catherine Tuff although the contact was not located in the map area (see discussion of Mount Catherine Tuff). South of the map area, along South Prairie Creek and on

the north slope of Burnt Mountain (E 19), in the southwestern part of the Enumclaw (15-min.) quadrangle, the formation was found in contact with the Stevens Ridge Formation. The upper contact of the formation is not well defined. The lava flows and breccia flows grade upward into predominantly epiclastic volcanic sediments of the conformable Huckleberry Mountain Formation. On the map the contact has been located atop the uppermost lava flow in a local area, or where a diagnostic unit in the lower part of the Huckleberry Mountain Formation was located, the contact was placed at the base of either unit or the lowest epiclastic volcanic rock exposed below the unit. The contact, therefore, is very irregular and does not represent a definite horizon. The contact zone is transitional and probably spans an interval of several hundred to possibly more than a thousand feet. To the east of Greenwater the Enumclaw Formation thins and the base of the Huckleberry Mountain Formation probably lies several thousand feet below the horizon of the contact in the extreme western part of the map. These relations are diagrammatically shown in plate 13.

Age and correlation.--Wolfe (1961) collected fossil leaves in the lower part of the Enumclaw Formation along the road on the south side of the Green River (U.S. Geological Survey locality 9693) and along a logging road on the south side of Coal Creek (U.S. Geological Survey locality 9682), and has determined the age of the enclosing strata as latest Eocene to early Oligocene

Fossil leaves were collected from the Enumclaw Formation at University of Washington localities A2300 and A2302 (see Appendix C). Most of the material was too fragmentary for identification. The following leaves were tentatively identified at locality A2300:

Viburnum sp.
?*Salix* sp.
Inflorescence

Additional fossil leaf material is available at the localities listed in Appendix C.

The Enumclaw Formation is considered to be late Eocene.

The lava and breccia flows of the Enumclaw Formation give way eastward to the epiclastic volcanic rocks which are assigned to the Huckleberry Mountain Formation. Farther eastward, near the Cascade crest, the lower part of the Huckleberry Mountain Formation is transitional with the micaceous arkosic sedimentary and coal-bearing rocks which characterize the "Naches Formation." The top of the Enumclaw Formation at Greenwater has been projected in the geologic cross-sections (pl. 2) and lies approximately on the same horizon as the Twin Creek Flow Member of the lower part of the Huckleberry Mountain Formation.

As mentioned previously the Enumclaw Formation includes the 2,400 feet of "Fifes Peak Formation" in Mount Rainier National Park and the lava flows above the basal tuffs of the "Upper Keechelus

Group" of Fisher (1957) southwest of the park.

Origin.--Within the map area the Enumclaw Formation has a minimum linear exposure of 60 miles north-south, extending from the Cowlitz River at the south to the Snoqualmie River at the north. The minimum exposure east-west is 20 miles and the formation probably includes the andesitic volcanic rocks unconformably overlying the Puget Group along the Cedar River (E 20) and along Fifteenmile Creek (E 21), west of the map area (Warren and others, 1945; Vine, 1962b). The flows probably do not extend much farther west, for Warren and others (1945) and Mullineaux (1961) have reported that marine volcanic clastic rocks unconformably overlie the Puget Group near Issaquah, along the northern slope of Newcastle Hill and at the eastern city limits of Renton along the Cedar River. This areal distribution suggests that the formation was deposited in a trough oriented approximately north-south. Very coarse breccia complexes are exposed sporadically and poorly in the area of the Three Sisters (E 22) in the Enumclaw (15-min.) quadrangle, in about the center of this trough. The breccia consists of angular to rounded pebbles to boulders, some as large as 10 feet in diameter, of varied colored and altered pyroxene andesite porphyry very similar to the flow rock which characterizes the Enumclaw Formation. The Weyerhaeuser Company locally quarries the knobby outcropping complexes for fill in constructing their logging roads. The exposures within the quarries indicate that the complexes are several hundred feet in diameter and the breccias occur as irregular zones cross-cut and surrounded by fresher dark-colored pyroxene andesite porphyry flow rock or hypabyssal intrusion. These breccias are the coarsest observed by the writer in the rocks of the Enumclaw Formation and appear to lack stratification. The writer is inclined to consider these breccias as vent breccias and suggests that this area may have been the source area for the flows. On the north side of The Three Sisters, south of Canyon Creek, the lava flows are interstratified with lenticular zones of very coarse breccia flows. In this area the breccias have been transported only a short distance. Transportation over a greater distance would comminute and break the fragments into the small block size characteristic of the breccia flows exposed north of the White River.

Huckleberry Mountain Formation.

Definition and type section.--An extensive and stratigraphically complex sequence of predominantly epiclastic volcanic rocks conformably overlies the Enumclaw Formation. This sequence is named herein the Huckleberry Mountain Formation. It consists of tuff-breccia and associated minor amounts of lapilli-tuff, lapilli-breccia and volcanic breccia, volcanic sediment, lava flows, breccia flows and tuff. It is the thickest and most widespread of all the formations comprising the Keechelus Volcanic Group within the map area. Locally it is overlain unconformably by the Eagle Gorge Andesite, Stampede Tuff, and Cougar Mountain Formation. The Huckleberry Mountain Formation is lithologically similar to the Snow Creek Formation overlying the Stampede Tuff, and if it were not for an intervening diagnostic tuff it would be impossible to distinguish the two formations, especially in the eastern part of the map area.

Several members have been distinguished within the Huckleberry Mountain Formation. They are the McDonald Point Tuff, Bear Creek Mudflows, Rack Creek Tuff, Champion Creek Tuff, Twin Camp Creek Flows, Tacoma Creek Flows and the Snowshoe Butte Flow. They are described under Petrography and Stratigraphic Sections.

The type section of the Huckleberry Mountain Formation is designated as the section exposed along the Christoff foottrail from Greenwater to the top of Huckleberry Mountain and from there northward along the western side of Wolf Creek to the contact with the overlying Eagle Gorge Andesite (HM 1). The section is best exposed along the upper part of Huckleberry Mountain and along Wolf Creek. The base of the formation is not exposed. The upper lava flows of the underlying Enumclaw Formation are exposed immediately west of Greenwater along U.S. Highway 410 (HM 2). The lowest unit exposed in the Huckleberry Mountain Formation along the Christoff trail is a dacite vitric crystal tuff (HM 3; see discussion of Petrography and Stratigraphic Sections). Tuff-breccia is exposed along the upper part of the southern slope of the mountain. Volcanic sediments are exposed along Wolf Creek. All the various rock types in the Huckleberry Mountain Formation are exposed in this section. None of the members of the formation could be traced into the section. The top of the formation was placed at the bottom of the flows assigned to the Eagle Gorge Andesite. It was located on aerial photographs.

Distribution and thickness.--The formation occurs mainly in the south-central and western parts of the map area (pl. 1). The formation extends eastward from Huckleberry Mountain to the eastern slope of the Cascade Range where it overlies the "Naches Formation." Remnants of the formation are preserved east of the upper Yakima River valley. The lower part of the formation may be present in the area between Chester Morse Lake and the western border of the Snoqualmie batholith in the north-central part of the map area, but here the rocks are so intensely contact metamorphosed, fractured and weathered that their stratification and lithologic features are greatly obscured. Most of the formation in the northern area has been either removed by pre-Cougar Mountain erosion, covered by the Cougar Mountain Formation, or engulfed by the emplacement of the Snoqualmie batholith. The formation extends southeastward from the Cascade crest into the southeastern part of the map area, into the drainage basin of the Naches River and beyond. The formation may include parts or all of the stratigraphically higher andesitic volcanic rocks in

Stout's (1959) "Naches Formation" and "keechelus type rocks." .

The formation ranges in thickness from 2,200 to 11,100 feet. North of Greenwater at Huckleberry Mountain the thickness is 2,970 feet. North of the North Fork of Taylor Creek in T. 22 N., R. 8 E., the preserved thickness is 2,200 feet. Along the south side of the Green River (HM 4; Appendix A) 4,570 feet were measured. At least 5,700 feet of strata are present along the Snowshoe Butte anticline between the top of the Blowout Mountain flows and the approximate position of the Stampede Tuff. A maximum thickness of 11,100 feet is exposed along the north side of the Green River in T. 21 N., R. 8 E. The erosional unconformity at the base of the overlying Eagle Gorge Andesite accounts in a large part for the wide range in thicknesses of the formation. Also, the formation thickens considerably to the west, from possibly more than 5,000 feet to over 11,100 feet (pl. 13).

Stratigraphic sections and petrography.--Partial sections of the lower part of the formation are well exposed along the road at West Twin Creek (HM 5). Very good exposures are located along Twin Camp Creek (HM 6). The lower part of the formation is excellently exposed along the ridges southeast and northwest of Blowout Mountain (see Appendix A) located along the Cascade crest in the southeastern corner of the map area. The lowermost part is also well exposed along the U.S. Forest Service road in the Gale Creek drainage basin (HM 7). A very well exposed section of the formation occurs along the Bear Creek road and railroad (HM 4; see Appendix A).

Tuff-breccia and associated lapilli-tuff, lapilli-breccia and volcanic breccia comprise most of the Huckleberry Mountain Formation. It is estimated that they form at least 75 percent of the rock types, volcanic sediments about 21 percent, thin lava and breccia flows 3 percent and widely scattered tuffs about 1 percent. The rock types are distributed uniformly throughout the extent of the formation. A small amount of micaceous arkosic and carbonaceous sedimentary rocks are included in the very lowest part of the formation along the upper Yakima River valley.

Several extensive and distinctive units were traced in order to correlate the stratigraphy and to determine the structures in the map area (pls. 11 and 13). The units distinguished in the western part of the area were not traced into the eastern part, and vice versa, except for an andesitic crystal vitric tuff, named the Rack Creek Tuff. Additional field work on the north slope of Huckleberry Mountain between Wolf Creek and the Green River may aid in extending the units. The units have been designated as members. The members occurring in the western part of the area are, from bottom to top, the McDonald Point Tuff, the Bear Creek Mudflows, the Rack Creek Tuff, and in the central part of the map area the Champion Creek Tuff. In the eastern part they are the Twin Camp Creek Flows, the Tacoma Creek Flows and the Snowshoe

Butte Flows. The units, with the exception of the Blowout Mountain Flow, and a few additional stratigraphic markers are described below in the order of their superposition, starting with those in the west.

At the base of the formation along the north side of the White River a thin light-olive gray dacite vitric-crystal tuff is exposed sporadically. Less than 50 feet of this tuff is exposed along the Christoff trail (HM 3). The rock is massive and contains about 12 percent fine- to medium-grained corroded quartz crystals, about 8 percent fine- to coarse-grained fractured plagioclase crystals, 5 percent greenish-black porphyritic pumice fragments less than ½ inch in diameter, and about 2 percent grayish-red-purple to dark-reddish-brown rounded lithic fragments, less than ¼ inch in diameter. The remainder of the rock consists of a devitrified vitroclastic groundmass. A similar tuff is present along the West Twin Creek road (HM 8) and farther west (HM 9). The tuff has an exposed thickness of about 50 feet in sec. 35 and about 20 feet in sec. 28. This is the only richly quartz-bearing tuff observed in the map area other than the Mount Catherine, Stampede and Kendall Tuff. The latter is located in the lower part of the "Naches Formation" along the east side of the upper Yakima River valley. The tuff was not found elsewhere near the base of the Huckleberry Mountain Formation. Additional field work, however, may reveal this unit to be more extensive.

East of West Twin Creek poor exposures prevent its being traced. The tuff may lie to the east within the 700-foot stratigraphic interval between the Twin Camp Creek Flows and the densely welded black andesitic crystal-vitric tuff underlying the Tacoma Creek Flows.

McDonald Point Tuff Member.--A fairly well-exposed and distinctive pale greenish-olive andesitic crystal-vitric tuff is exposed at the base of the Huckleberry Mountain Formation along the north side of the Green River (HM 10) and along the McDonald Point road (HM 11). The tuff is named the McDonald Point Tuff but is incompletely exposed at this locality. Only a 50-foot section of tuff crops out at a distance of about 150 feet below the base of the Bear Creek Mudflow Member. It overlies a dark-gray pyroxene andesite porphyry flow which is the top of the Enumclaw Formation. The McDonald Point Tuff is much better exposed in the road cuts along the north side of the Green River (HM 10). Here the tuff is at least 250 feet thick. The lower 100 feet is a pumice crystal-vitric tuff. The pale olive to grayish-olive pumice fragments are flattened, less than one inch long and impart a weakly developed eutaxitic layering. The jointing is very irregular. The lower part is overlain sharply by a well indurated pumice crystal tuff-breccia, containing a small percentage of altered pyroxene crystals. The tuff-breccia is about 150 feet thick and has well-developed eutaxitic layering and columnar jointing.

In general the McDonald Point Tuff contains up to 30 percent crystals (spec. 8). As much as 5 percent of the crystals are almost completely altered pyroxenes (augite?); the remaining is plagioclase which is partly replaced by calcite. Pumice fragments make up as much as 10 percent of the rock and commonly contain plagioclase phenocrysts. Lithic fragments comprise up to 5 per cent; they are rounded, and colored medium bluish gray to dusky blue. Almost all the fragments appear to be vitrophyres. The matrix is cryptocrystalline. Columnar jointing and eutaxitic layering are locally well developed.

The McDonald Point Tuff is sporadically exposed. Its southernmost extent is about one mile southeast of Grass Mountain (HM 12), where it occurs along a small creek and is believed to lie about 200 feet above the dacite vitric-crystal tuff of sec. 28. In the area between the North Fork of the Green River and the Green River (pl. 1) the tuff has served as a marker bed to determine the approximate base of the Huckleberry Mountain Formation and to unravel the structure (pl. 2 B-B'). About 75 feet are exposed along the road east of Boundary Creek (HM 13), and more than 100 feet in the area between the North Fork of the Green River and Boundary Creek (HM 14). More than 100 feet is exposed in the drainage basin of Piling Creek (HM 15). North of the North Fork of Taylor Creek (HM 16) 25 feet is exposed; it is grayish purple colored, and more than 200 feet is present in the outcrop to the east (HM 17). In the latter area the tuff lies as much as 1,600 feet above the highest lava flows of the Enumclaw Formation. The McDonald Point Tuff has an areal extent of about 14 miles north-south and 6 miles east-west.

Bear Creek Mudflow Member.--An unusually well-exposed sequence of lithic volcanic breccia, pumice breccia and tuff-breccia crops out along the railroad above Bear Creek (HM 18). This unit is named herein the Bear Creek Mudflow Member. It has a maximum exposed thickness of 1,300 feet; neither the top nor bottom is exposed. It consists of at least five distinctive mud-flow units, each showing crudely graded bedding and characterized by slight differences in lithology. The lithic breccia at the base is the most diagnostic lithology of the member and its recognition elsewhere is the main criteria for extending the member. At Bear Creek the deposits are intruded by irregular dikes 5-20 feet thick of greenish-black pyroxene andesite porphyry. A stratigraphic section of the member is shown as a part of the Huckleberry Mountain Formation in Appendix A. A hand specimen of lithic-pumice tuff-breccia is shown in plate 6B. The member is less well exposed along the road immediately to the north.

About 50 feet of the basal lithic tuff-breccia is exposed on the McDonald Point road (HM 11). Here the lithic fragments are subangular to rounded, fine pebble to boulder up to two feet in diameter, and consist of about 35 percent dark-gray andesite porphyry, 10 percent gray flow-layered aphanite, 5 percent dusky-red to reddish-brown flow-layered andesite porphyry, and 2 per cent light-greenish-gray pumice fragments.

About 125 feet of similar rock, grading from large boulder lithic tuff-breccia upwards into a cobble lithic tuff-breccia, occurs in the road cuts northwest of Grass Mountain (HM 19). The basal well-indurated part of the mudflow is also exposed in the drainage basin of Gale Creek (HM 20) where it outlines the fold of the Snowshoe Butte anticline.

About 150 feet of lithic tuff-breccia is exposed along the North Fork of Taylor Creek (HM 21).

The Bear Creek Mudflow Member lies about 1,470 feet above the base of the Huckleberry Mountain Formation along the Green River, 530 feet above at Gale Creek, and 1,700 feet above at the North Fork of Taylor Creek. The unit has a north-south extent of 11 miles and east-west for 8 miles. The large carbonized tree fragments in the mudflows at Bear Creek are oriented approximately WSW-ENE. Further study of this member may reveal the direction of its movement.

Rack Creek Tuff Member.--A diagnostic crystal-vitric tuff of fairly wide extent was first noted underlying the Stampede Tuff in the drainage basins of Rack Creek and the North Fork of Taylor Creek. Subsequently it was located along the McDonald Point and Bear Creek roads, northwest of Grass Mountain and underlying the Cougar Mountain Formation north of the Green River in the central part of the map area. A very similar tuff occurs below the Stampede Tuff and above the Snowshoe Butte Flows south of Borup Creek (HM 22), in the eastern part of the map area and is tentatively correlated with the Rack Creek Tuff. This unit is the only one which has been traced across the map area within the Huckleberry Mountain Formation. It is named the Rack Creek Tuff for its exposure east of Rack Creek (HM 23). Here the tuff is about 200 feet thick, well indurated near its base, and is medium yellowish-brown, becoming greenish toward the top. It is essentially an andesite crystal-vitric tuff in the lower part and grades upward into a lithic pumice crystal tuff-breccia. It has good eutaxitic layering and blocky jointing. It overlies massive green tuff-breccia with a well-defined disconformity and immediately underlies the Stampede Tuff although the contact is not exposed. About 17 feet is preserved beneath the Stampede Tuff along the west side of the North Fork of Taylor Creek (HM 24). Along the McDonald Point road (HM 25) the tuff is 110 feet thick and overlies the Bear Creek Mudflow Member by about 400 feet.

The tuff is best exposed along the Bear Creek road (HM 26). Here it is more than 300 feet thick; the top and bottom are not exposed. The basal 150 feet is dark greenish gray, dense rock of which a hand specimen very much resembles an aphanite flow rock (spec. 9). Microscopically it is andesite crystal-vitric tuff.

It contains about 10 percent plagioclase crystals, about ¼ mm in size, which are corroded, have oscillatory zoning and a composition of An_{23-58}. About 2 percent of the rock is altered augite crystals. The rock contains about 3 percent lithic fragments, mainly of flow rock types, and 2 percent flattened pumice fragments. The crystals and fragments are embedded in a brown feebly devitrified, highly compressed vitroclastic groundmass. The basal part is overlain by a 50-foot zone of light-olive-gray pumice crystal-vitric tuff. The tuff of this zone contains about 15 percent plagioclase, about 10 percent light olive-gray very well-flattened, up to 2 inches long, porphyritic pumice fragments, forming a good eutaxitic layering, and less than 5 percent subangular, up to ¼ inch in diameter, brownish-black to moderate yellow lithic fragments. This zone is in turn overlain by a 75-foot zone of mottled pale yellow-brown to moderate yellow-brown pumice crystal-vitric tuff (pl. 9). The pumice fragments are light olive-gray, porphyritic, and up to 5 inches long and one inch thick. The mottling is believed due to patchy devitrification. The upper 25 feet is distinguished by numerous grayish-brown vitrophyre fragments as well as pumice fragments.

About 250 feet of Rack Creek Tuff are exposed along the roads northwest of Grass Mountain (HM 27). Lithologically similar tuff is exposed in a small pit in the Bonneville Power Administration power line right-of-way north of Maywood (HM 28), and underlying basal boulder conglomerate of the Cougar Mountain Formation along the U.S. Forest Service road between Cougar and Sylvester Creeks (HM 29). Only 20 feet of this tuff is exposed along the road at the West Fork of Smay Creek (HM 30).

The easternmost outcrops of tentatively correlated Rack Creek Tuff occur along the Borup Creek road (HM 22). Only the basal 20 feet is exposed here. The tuff is weathered and is gray to pale red purple to grayish blue green in color, but the outlines of the plagioclase crystals and scattered, flattened pumice fragments are distinctive. It overlies deeply weathered pumice lapilli-breccia and tuff-breccia. The basal unconformable contact is well-exposed. The tuff lies stratigraphically 300 feet below the Stampede Tuff.

Flow of dark-gray fine-grained holocrystalline andesite is well exposed in a quarry along the Bear Creek road (HM 31). It lies 450 feet stratigraphically above the Rack Creek Tuff and is about 200 feet thick. The flow is massive to flow layered, has a well-developed platy to blocky jointing with large curved joint faces. It contains many interbreccia zones in which the rock is highly altered to a moderate red soft mass. Microscopically the rock consists of about 88 percent plagioclase (An_{32-38}) laths, 10 percent anhedral augite and 2 percent granular magnetite, and has a trachytic texture (spec. 10). The same flow is exposed east of the Howard A. Hanson dam and north of the Lemolo fault (HM 32). Here it has an exposed thickness of about 400 feet.

Champion Creek Tuff Member.--A pale grayish-blue-green lithic-crystal-vitric tuff, deeply altered and punky, es exposed along Champion Creek (HM 33), and is named herein the Champion Creek Tuff. It has a maximum exposed thickness of 300 feet; the top and bottom are not exposed. It contains about 5 per cent grayish-blue-green pumice, and about 10 percent grayish-blue rounded lithic fragments less than one inch in diameter (spec. 11). It contains about 30 percent crystals of which at least 25 percent are extensively altered. Up to 5 percent of the crystals were probably originally pyroxenes that have subsequently been altered to chlorite or an unidentified green mineraloid. The mineraloid is also common in the cryptocrystalline groundmass. The remaining crystals are plagioclase. About 20 feet of the tuff are exposed near the top of Huckleberry Mountain at the head of West Twin Creek (HM 34). At both localities the tuff is underlain by more than 100 feet of very well-bedded volcanic sediments, most of which are coarse-grained volcanic sandstone. From the ridge top in the NW¼ sec. 10, T. 19 N., R. 10 E., the tuff and the underlying light-colored sediments can be traced from their exposures at Champion Creek southeastward along the homoclinal dip into the drainage basin of Rack Creek to about the 3,500-foot elevation below Kelly Butte in sec. 2. The same strata are probably exposed in the landslide scar at the head of Slide Creek in the SE¼, sec. 9.

The Champion Creek Tuff lies about 3,700 feet above the base of the Huckleberry Mountain Formation. It is not exposed in the section at Bear Creek to the west where the formation is 4,590 feet thick. The tuff may have been deposited in the Bear Creek area. If it had, it probably had overlain the volcanic sediments exposed along Bear Creek (HM 35) below the contact with the overlying Eagle Gorge Andesite. The formation thickens westward; therefore, the tuff would be here at a higher stratigraphic level. The tuff lies about 530 feet below the Eagle Gorge lava flows at the head of West Twin Creek. West of here the tuff would have been removed by erosion prior to accumulation of the flows.

The basal part of the Huckleberry Mountain Formation is well exposed at Blowout Mountain along the Cascade crest in the southeastern corner of the map area. About 3,200 feet of section is exposed along the ridge to the southeast to the top of the mountain (see stratigraphic section in Appendix A). The lower 1,075 feet is exposed along the southeastern ridge of Blowout Mountain. The strata consist entirely of volcanic rocks and form the southwestern flank of the Snowshoe Butte anticline. The micaceous arkosic sediments characteristic of the underlying "Naches Formation" are exposed in the core of the fold in the saddle at the southeastern end of the ridge. About 580 feet above the arkosic strata along the eastern side of the saddle (HM 36), an 85-foot lava flow, named herein the Blowout Mountain Flow, is exposed. This flow probably did not extend any great distance to the west, inasmuch as it is not exposed on the ridge southeast of Blowout Mountain. Here the same stratigraphic interval is occupied by the upper 25 feet of a 145-foot section of pale grayish-green crystal pumice tuff-breccia (see Appendix A). The Blowout Mountain Flow is designated as the top of the "Naches Formation" and the overlying volcanic strata are assigned to the Huckleberry Mountain Formation of the Keechelus Volcanic Group. The flow is very similar lithologically to the Rampart Ridge Porphyry Flows which are designated herein as the top of the "Naches Formation" in the upper Yakima River valley (see discussion of "Naches Formation").

The disconformity between volcanic sediments and lava flows, illustrated in plate 10B, is exposed in the upper 420 feet of section exposed on the northeastern face of Blowout Mountain. The section of flows is about 45 feet thick and consists of possibly 2 or 3 thin flow units, suggested by their irregular stratification and inclination of the tiers of columnar jointing. The flows extend northwestward of Blowout Mountain (HM 37) and consist of flows with thin interbreccia zones. The rock is dark-gray fine-grained basaltic andesite, containing plagioclase, augite, magnetite, and some chlorophaeite(?) in a pilotaxitic groundmass.

<u>Twin Camp Creek Flow Member</u>.--The Twin Camp Creek Flows, named for the flows exposed along Twin Camp Creek (HM 38), are about 400 feet thick. The flow rock is a medium

dark-gray very fine-grained porphyritic andesite (spec. 12). It consists of about 75 percent plagioclase, which are largely replaced by calcite, 10 percent augite, most of which is pseudomorphed by fibrous chlorite, 10 percent granular magnetite, and about 5 percent a yellowish-green unidentified mineraloid. The texture is intergranular to pilotaxitic. The flows can be traced westward for about 2 miles to Colquhoun Peak. They may underlie the ridge between Burns and Whistler Creeks 2 miles west of Colquhoun Peak. They cannot be traced further westward. They extend eastward along the north side of Twin Camp Creek. Their total linear outcrop is about 3½ miles.

The flows have been projected eastward in the geologic sections (pl. 2G-G', H-H', I-I' and J-J') and lie at about the same stratigraphic horizon as the Blowout Mountain Flow. In this area the flows are designated as the base of the Huckleberry Mountain Formation. The underlying strata, exposed mainly on the U.S. Forest Service road to Pyramid Peak (HM 39), consist of volcanic sediments. The sediments lie about midway in the lithologic gradation between the Enumclaw Formation to the west and the "Naches Formation" to the east.

A distinctive black crystal-vitric tuff is very poorly exposed along Twin Camp Creek (HM 40). This tuff is very similar lithologically to the andesite vitric tuff of the Sunday Creek Tuff Member in the stratigraphically higher Snow Creek Formation. It lies about 1,000 feet stratigraphically above the Twin Camp Creek flows. Similar rock was noted as float along Tacoma Creek at its junctions with the Green River and Pioneer Creek to the east. Similar rock also occurs as float below the western face of Cole Butte above the lake along the eastern border of the map area. There is a possibility that these outcrops may be of an equivalent tuff unit.

Tacoma Creek Flow Member.--The Tacoma Creek Flows are exposed along the north side of Tacoma Creek. They are about 250 feet thick and lie 700 feet stratigraphically above the Twin Camp Creek Flows. The flow rock is a medium-dark-gray, weathering to an olive-gray, andesite porphyry (spec. 13). The phenocrysts average one mm in size and consist mainly of plagioclase (An_{15-50}) which is commonly altered to calcite and sericite. The groundmass is intergranular, consisting of plagioclase laths, granular augite and magnetite and fibrous chlorite(?). Plagioclase constitutes about 78 percent of the rock, chlorite(?) 10 percent, augite 7 percent, and magnetite about 5 percent. The flow can be traced in the field and on aerial photographs for a distance of about 4 miles.

Snowshoe Butte Flows Member.--A highly resistant and well-exposed sequence of aphanite flows caps Snowshoe Butte and extends northwestward along the northwestern slope of the butte to Sunday Creek in T. 20 N., R. 11 E. This sequence is named the Snowshoe Butte Flows and consists of two or more lava flow units. The flow rock is a grayish-black porphyritic andesite (spec. 14). It contains about 10 percent phenocrysts in a merocrystalline trachytic groundmass with interstitial brown glass. Most of the phenocrysts are plagioclase which are oscillatory zoned and consist of An_{42-57}. The remaining are brown augite. The flows are about 400 feet thick and extend for about 4½ miles. They lie stratigraphically about 2,000 feet above the Tacoma Creek Flows and underlie the eastern extension of the Rack Creek Tuff by about 150 feet.

Contact relations.--The lower contacts of the Huckleberry Mountain Formation are conformable and transitional with the Enumclaw and "Naches" Formations. The contact with the Enumclaw is not well defined. As mentioned previously, the contact is placed above the upper lava flow, in a local area at the base of the lowest member in the Huckleberry Mountain Formation, or at the base of the lowest exposed epiclastic volcanic rock below the member. Along the Green River and McDonald Point road in T. 21 N., R. 8 E., and in the Boundary and Piling Creeks area the contact is placed at the base of the McDonald Point Tuff. Along the north side of the White River the contact is located below the dacite crystal-vitric tuff. North of the North Fork of Taylor Creek and south of Chester Morse Lake (HM 41) the contact is placed atop the highest lava flow constituting a part of a thick underlying sequence of flows. The contact is not a horizon but lies within a stratigraphic interval which ranges from a few hundred to possibly more than one thousand feet throughout the western part of the map area. In the southeastern part of the map area the base of the formation is designated as the Twin Camp Flow Member.

The contact with the "Naches Formation" is placed atop the Rampart Ridge Porphyry Flows along the west side of the upper Yakima River valley and atop the Blowout Mountain Flow in the Blowout Mountain area. The contact has been extended southwestward and southward on scanty field evidence and uncertain aerial photographic interpretation from the exposure of the Rampart Ridge Porphyry Flows along the Northern Pacific Railroad (HM 42). It passes through the head of the Cabin Creek drainage basin to the Cascade crest at Tacoma Pass and southward from there along the crest through the head of the west fork of Log Creek to Blowout Mountain. A lower part of the formation may be present in the trough of the Log Creek syncline along Big Creek in T. 19 N., R. 13 E.

The upper contact is better defined. It lies at the base of the unconformably overlying Eagle Gorge Andesite, Stampede Tuff and Cougar Mountain Formation. The contact with the Eagle Gorge Andesite is well exposed (HM 43) east of the Howard A. Hanson dam (see discussion of Eagle Gorge Andesite). The contact can be located within a few tens of feet along the east side of Bear

Creek (HM 35), along the Grass Mountain road east of Lynn Lake (EG 7), and just north of the head of West Twin Creek (HM 44). The contacts along the north side of the Green River are concealed by extensive surficial deposits.

The location of the Stampede Tuff and consequently the top of Huckleberry Mountain Formation is inferred on aerial photographic interpretation between the pyroxene andesite porphyry dike complex at T. 20 N., R. 10 E., and Snow Creek, north of the Green River.

The contacts with the Stampede Tuff are well exposed along the west side of the North Fork of Taylor Creek (HM 45) and just west of Lizard Lake at Stampede Pass (ST 1). The contacts can be approximately located at the divide between Rack and Taylor Creeks (HM 46), along the north side of the Green River (HM 47), and along the Borup Creek road (HM 48) (see discussion of Stampede Tuff).

The contacts with the Cougar Mountain Formation can be placed only approximately. Along the West Fork of Smay Creek (HM 49) an approximate 260-foot thick basal flow of the Cougar Mountain overlies by as much as 500 feet the uppermost exposure of the Huckleberry Mountain Formation which consists of a dusky-blue-green lithic pumice tuff-breccia atop a 75-foot section of fossil leaf-bearing volcanic sediments (UWA 2303). North of Gale Creek (HM 50) altered lava flows and breccia flows of the Cougar Mountain Formation overlie thin lava flows of the Huckleberry Mountain

Formation. The contact along the North Fork of the Green River in T. 21 N., Rs. 8 and 9 E., is partly inferred on aerial photographic interpretation and physiographic expression. To the northwest the contact is placed at the base of the steep slope below Ghost Point. The contacts with the Cougar Mountain Formation in the northern part of the map area are located along stream valleys.

Age.--Leaf fossils were collected from two localities, University of Washington A 2303 and A 2306, in strata of the formation, shown on the map (pl. 1) and listed in Appendix C. The leaves are tentatively identified as follows:

A 2303

?*Acer* sp.
?*Tilia aspera*
?*Populus* sp.

Only conifer needles were identified at locality A 2306.

The Huckleberry Mountain Formation is considered to be late Eocene. The formation is interstratified with the Enumclaw and "Naches" Formations of probable late Eocene age.

Additional leaf fossils occur at the locations listed in Appendix C.

The transitional relationships of the formation with the underlying Enumclaw and "Naches" Formations indicate that the Huckleberry Mountain Formation is closely related in age and is, therefore, about latest Eocene to early Oligocene.

Origin.--The formation consists largely of fragmental volcanic rocks which were in a large part ejected explosively from large volcanic centers in prodigious quantities. They were probably dispersed from these centers by predominantly fluvial processes and subordinately by prevailing winds. Winds could have carried the material tens to as much as a hundred miles from these sources. At their initial site of deposition most of the ejecta were probably incorporated, reworked and deposited as epiclastic rocks. The mudflow deposits could consist of debris transported directly from the flanks of the volcanoes or of wind-transported clastics. Mudflows are known to extend as much as 50 miles from a volcano (Crandell and Waldron, 1956). Inasmuch as the bulk of the formation consists of mudflow deposits the formation could be composed of ejecta derived from sources within the map area or closely adjacent to it. No evidence of the eroded root of a large explosive volcanic center was found in the area. Some or most of the material could have come from the possible volcanic center in the Three Sisters area south of the White River. The thin lava flows could have been derived from these centers as well as from many fissures now exposed as the myriads of dikes of altered hypabyssal rocks in the area.

Eagle Gorge Andesite.

Definition and type section.--A thick section consisting predominantly of andesite lava flows unconformably overlies the Huckleberry Mountain Formation in the western part of the map area (pl. 1). It is herein named the Eagle Gorge Andesite. The formation consists of lava flows, breccia flows, and very minor amounts of tuff-breccia and tuff. An extensive complex of subaqueous breccia is present along the Green River between the Howard A. Hanson dam and Humphrey. The formation extends along the Green River from Bear Creek eastward to just beyond Wolf Creek, a distance of about 12 miles.

The formation constitutes the middle sequence of the Keechelus Volcanic Group. Although it does not crop out in the Snoqualmie Pass quadrangle, it is "sandwiched" between the sequences that are exposed there.

The type section is designated as the section exposed from Bear Creek eastward to Eagle Gorge, along the south side of the Green River valley near the Howard A. Hanson dam (EG 1). The rocks are discontinuously although well exposed in cuts along the road. Lava and breccia flows are exposed between Bear Creek and the south side of Howard A. Hanson dam. To the east the section consists predominantly of subaqueous breccias (see discussion of petrography). The lava flows and breccias dip gently eastward. The lava flows are exposed to the south and eastward beyond Eagle

Gorge. The base of the formation can be approximately located at Bear Creek (EG 2; see discussion of contact relations). The top of the formation is not exposed in the immediate area.

Thickness.--The formation has a maximum exposed thickness of 4,150 feet along the north slope of Grass Mountain north to Eagle Gorge. Only 730 feet is preserved near Wolf Creek at its eastern extent.

Petrography.--The lava flows form thin flow units. The flows exposed in the railroad cut west of Humphrey (pl. 6A; EG 3) are 15 to 25 feet thick; the intervening breccia flows are 15 to 30 feet thick. The contacts with the breccia flows are sharp. The base of a breccia may be marked by a 1-2-foot dark-reddish brown alteration or saprolite zone. The flows are commonly platy jointed with large curved faces. The flow rock is dark gray to grayish black and weathers to a grayish red. It is essentially a pyroxene andesite porphyry very similar to the common flow rocks in the Enumclaw Formation (spec. 15). It consists of medium- to fine-grained prismatic plagioclase and a fewer number of equant altered augite phenocrysts in a very fine-grained pilotaxitic to intergranular groundmass of feldspar microlites, augite, magnetite and chlorophaeite(?). The phenocrysts compose up to 30 percent of the rock. The ratio of plagioclase to augite is about 5:1. The plagioclase has oscillatory zoning and has a composition of An_{48-65}. The augite crystals are altered to aggregates of calcite, chlorite, magnetite and some chlorophaeite(?). The chlorophaeite(?) occurs commonly as clots with a rim of radial chlorite. The breccia flows are commonly altered and are greenish gray. The fragments are angular to subrounded, range in size from 3 inches to 2 feet in diameter with the average about 6 inches, and are colored grayish olive-green to pale red. Intensive alteration has coverted the fine breccia fragments to soft irregular masses of pale olive to grayish yellow-green. The larger breccia fragments contain relatively fresh pyroxene andesite porphyry. The breccias exposed along the south side of the Green River at the Howard A. Hanson dam site are intricately intruded by irregular dikes of pyroxene andesite porphyry. The dike rock is deuterically altered. The deuteric alteration probably contributed to the alteration of the enclosing brecciated flow rocks.

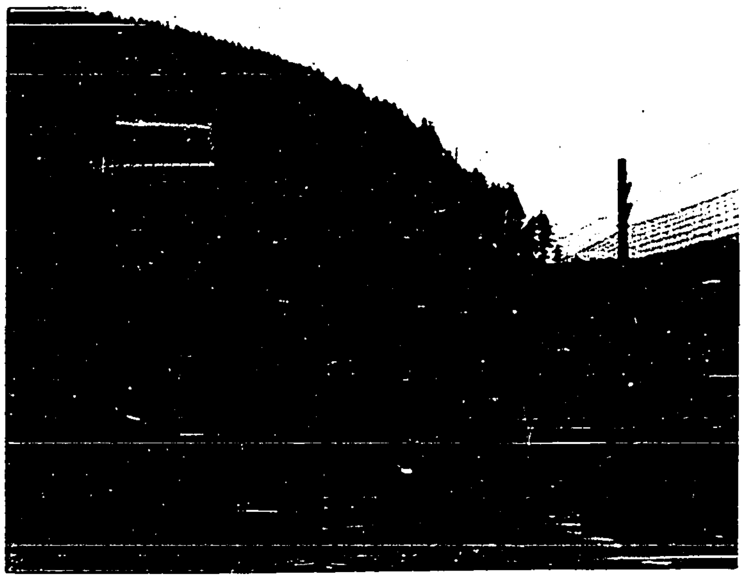
Massive subaqueous breccias are well exposed along the road near Eagle Gorge (EG 4). At first examination the outcrops appear to consist of massive broken rock of uniform composition. From a distance, however, a crude stratification dipping gently to the east can be detected (pl. 16A). The breccia mass has a somber light-olive-gray color and is composed largely of angular blocks from a few inches to many feet in diameter. The rock is deeply altered yet the texture characteristic of the fresh flow rock is preserved. Scattered throughout the breccia mass are very large rounded blocks 5-20 feet in diameter that are composed entirely of

PLATE 16

Subaqueous breccia of Eagle Gorge Andesite

A. Outcrop of the upper part of the formation at the type section in the NE¼ sec. 35, T. 21 N., R. 8 E. Looking southwest. Bedding can be discerned in center, dipping about 30° E.

B. Close-up of outcrop directly beyond vehicle in above photograph. Height of outcrop about 50 feet. Note rounded blocks of radially columnar-jointed flow rock in center. Largest block is about 20 feet in diameter.



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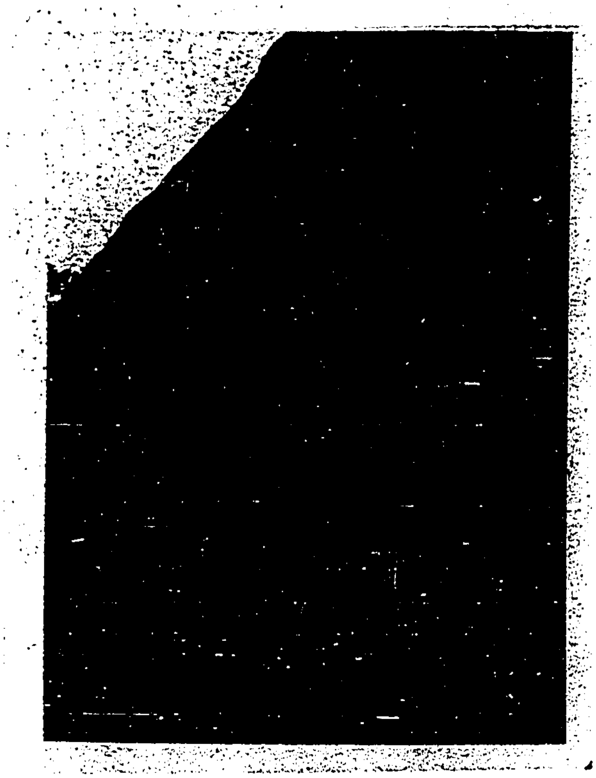


B

PLATE 16

concentrically radiating, small wavy columns about 4 inches in diameter (pl. 16B). A ¼-inch rind is present at the ends of the columns. Most of the rinds, however, have weathered to clay. The breccia has a maximum exposed thickness of 300 feet but may be thicker. It appears to lie in the upper part of the formation. Atop the mass, to the left of the view in plate 16A, unaltered well-fractured lava flows conformably overlie the breccia. From the road a spiracle can be seen extending from the breccia up about 20 feet into the overlying lava flow. The crude stratification, the uniform alteration, the ball-like blocks with radial jointing inside and a peripheral rind, and the spiracle into the overlying flow suggest that the breccias were produced by movement of lava flows into water, either into a stream, shallow lake or upon swampy terrain. Consequent brecciation and alteration was produced by steam explosions and concomitant gaseous steeping of the broken masses. Locally, along the road cut shown on the left side of plate 16A, the breccia is intensely altered to a mottled mass of moderate yellow, pale olive, dark reddish brown and brownish black. Considerable hematite, "limonite," and probable jarosite are present. Disseminated fine-grained pyrite is abundant. Widely spaced irregular veins of chalcedony cross-cut the alteration. This alteration may have been caused by subsequent fumarolic or deuteric solutions derived from the emplacement of the dikes near the Howard A. Hanson dam. West of the subaqueous breccias described above (EG 5), near Eagle Gorge, and along the railroad and road to the east (EG 6), massive yellowish-gray breccias are exposed. The fragments are predominantly angular to subrounded, up to 6 feet in diameter. The flow rock is aphanitic and flow layered. Carbonaceous debris is present. Field criteria for determining their origin of the yellowish-gray breccias are lacking but their association with the subaqueous breccias suggest that they were also formed largely by steam brecciation and concomitant alteration.

Contact relations.--The contacts of the Eagle Gorge Andesite are not well exposed. Along Bear Creek (EG 2) the basal lava flow crops out about 50 feet above the level of Bear Creek. Considerable slough covers the slope below so volcanic sediments of the Huckleberry Mountain Formation only are exposed at the creek. From there northwestward the creek follows the approximate contact between the two formations. Northeast of Grass Mountain (EG 7) the base of the Eagle Gorge Andesite is marked by a dark-gray pyroxene andesite porphyry flow overlying a calcified grayish-green andesite porphyry flow of the Huckleberry Mountain Formation. The contact is not exposed.

Isolated outcrops of Eagle Gorge Andesite flow rock are exposed along the road on the northeast side of the Howard A. Hanson dam (EG 8). Dark-reddish-brown altered breccia flows truncate platy porphyritic andesite lava flows, thin-bedded volcanic sandstone, and the dark-gray fine-grained andesite flow which lies stratigraphically above the Rack Creek Tuff of the Huckleberry Mountain Formation. The breccia flows extend down to the foot of the slope exposed along the north shore of the lake impounded by the Howard A. Hanson dam. They are separated from similar breccia flows underlying the hill in the middle of the valley (EG 9) by the Lemolo fault which trends eastward along the Green River valley. The relative differences in the position of base of the Eagle Gorge Andesite upon the underlying stratigraphic units of the Huckleberry Mountain Formation along the north side and south side of the Green River valley in this area suggests that the flows were deposited upon an irregular surface with as much relief as 450 feet. Absence of the Champion Creek Tuff at Bear Creek also suggests that there was considerable relief buried by the Eagle Gorge flows. The stratigraphic gap between the Eagle Gorge Andesite and the Huckleberry Mountain Formation between Champion and Bear Creeks suggests that as much as 1,600 feet of relief existed atop the Huckleberry Mountain Formation. However, this figure does not take into consideration the amount of structural deformation, if any, in the area following deposition of the Huckleberry Mountain Formation.

Movement along the Lemolo and Piling Creek faults along the north side of the Green River valley between the North Fork of the Green River and Gale Creek has truncated the northern extent of the Eagle Gorge Andesite

The erosional interval which preceded deposition of the Stampede Tuff removed the Eagle Gorge Andesite along the north side of the Green River between Gale Creek and Green Canyon. The tuff was not located in contact with the Eagle Gorge. The closest point at which the two units are in contact is along the road south of Green Canyon (EG 10), where outcrops of the two are separated by about 30 feet. Northwest of Humphrey (EG 11) a covering of glaciofluvium spans an interval of about 500 feet between the hill of Eagle Gorge lava flows and outcrops of Stampede Tuff to the east. Near the bridge across the Green River (ST 13), west of Maywood, the tuff crops out at the road about 40 feet above the Green River. Here flows of the Eagle Gorge Andesite are exposed in the bedrock and along the south side.

Age.--No leaf fossils or leaf impressions have been collected from the strata of the Eagle Gorge Andesite. The formation is considered to be of late Eocene age; it is "sandwiched" between two sequences of the Keechelus Volcanic Group which range from late Eocene to early Oligocene.

Origin.--The lava and breccia flows of the Eagle Gorge Andesite are lithologically similar to the flows of the underlying Enumclaw Formation. However, the flows of the Eagle Gorge Andesite do not appear to be as thick and are not interstratified with thick quantities of epiclastic rocks. Rather, the lack of intercalated fragmental ejecta and the uniformity of composition and texture suggest that the lava flows were derived largely from fissures. Much of the formation may have been removed by erosion during the interval prior to deposition of the Stampede Tuff, so the formation may have had greater areal extent at one time. The location of the fissures from which the flows may have been derived is undetermined.

Stampede Tuff.

Definition and type section.--A unit of dacite crystal-vitric tuff and a subordinate amount of pumice tuff-breccia and lithic tuff-breccia has been traced throughout much of the map area. The unit is herein named the Stampede Tuff. The lithologic features of the unit vary subtly from east to west but serve as criteria for correlating the scattered exposures. Study of stratigraphic sections of the unit reveals that the formation is a composite ignimbrite and had accumulated as an ash-fall tuff deposit. At least four separate tuff units, designated as zones, compose the formation. This tuff is the most diagnostic stratigraphic marker of the units in the Keechelus Volcanic Group. Tracing of the tuff has served to unravel several structural complications, especially in the Lake Keechelus area. It forms the lower unit of the upper sequence in the group. It unconformably overlies the "Naches" and Huckleberry Mountain Formations and conformably underlies the Snow Creek Formation. The outcrop pattern of the formation outlines the structural depression in the central part of the map area.

The type section of the Stampede Tuff is designated along upper Sunday Creek (ST 1), west of Lizard Lake near Stampede Pass. The base is exposed at the road and the top occurs about 1,500 feet upstream (ST 2). The unconformity at the base is well exposed along the creek. The top of the tuff is overlain conformably by volcanic sediments of the Snow Creek Formation. At the type section the formation consists mostly of dacite crystal-vitric tuff. The base consists of 20 feet of pumice crystal-vitric tuff-breccia. The section is zone 3 of the formation, as shown in plate 19. The stratigraphic section at the type locality is shown in Appendix A. The other zones, composing the formation, are shown diagrammatically in plate 19. The zones are discussed under stratigraphic sections. Additional locations, which serve as reference sections, are also shown in plate 19.

<u>Distribution and thickness</u>.--The tuff extends from Lake Keechelus in the east to the drainage basin of the North Fork of Taylor Creek in the west. It is well exposed along Roaring Ridge, west of Lake Keechelus, near Stampede Pass and along Sunday Creek. It is sporadically exposed along the Green River valley and in the drainage basin of Gale Creek. It has been removed by the pre-Cougar Mountain erosional interval in the north-central part and engulfed by Snoqualmie granodiorite in the northeastern part of the map area.

The vent zone and source of the tuff is located at the north end of the outcrop (ST 3) along the east shore of Lake Keechelus.

The unit has an areal extent of 23 miles east-west and 13 north-south. To the writer's knowledge the tuff is not exposed outside the Green River structural depression. The unit may have extended outside the map area and now possibly is preserved in a structural depression south of the Tatoosh high (see discussion on Structure) in Mount Rainier National Park and along the eastern flank of the Cascade Range south of the Naches River. However, the lithologic features--lateral variation in constituents and thickness--suggest that the tuff may not have had an areal range of over 50 miles radius from the vent zone at the east shore of Lake Keechelus and at the present time lies wholly within the map area (pl. 1).

The tuff is irregular in its thickness. It has a maximum exposed thickness of 2,820 feet at Lake Keechelus where the top is not preserved. It is 240 feet along the North Fork of Taylor Creek (ST 4). Only 40 feet are exposed on Sunday Creek (ST 5).

Petrography.--The Stampede Tuff consists predominantly of dacite crystal-vitric tuff. Lesser amounts of pumice and lithic fragments ranging in size from tuff to breccia occur locally and serve to distinguish the various zones in the formation.

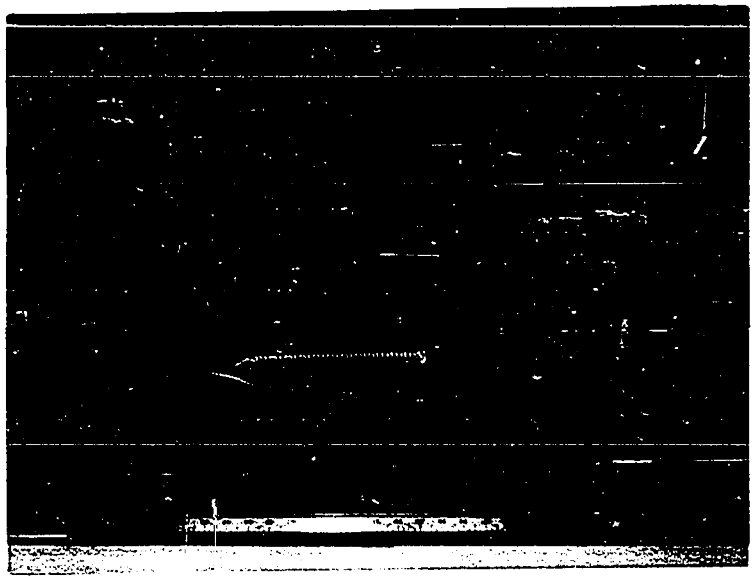
The dacite crystal-vitric tuff composes about 70 percent of the unit. In outcrop it is commonly massive but at closer inspection an incipient foliation can be detected. Bedding can generally be determined by the scattered partially flattened pumice fragments. This tuff contains 20-30 percent crystals, of which 10-20 percent of the rock are plagioclase, and 5-10 percent quartz (spec. 16). About 1 percent each of augite and magnetite are present; about 5 percent pumice and 3 percent lithic fragments are accessories (pl. 17A). The color of the tuff ranges from a dark greenish gray to pale olive to grayish yellow green. To the west (west of the exposures near Green Canyon) the tuff tends to be lighter colored, ranging from pale olive to greenish gray to yellowish gray. The crystal percentage lessens, consisting of 15-20 percent of the rock; 7-10 percent and 5-12 percent are plagioclase and quartz, respectively (spec. 17; pls. 17B and 18A). The other constituents are about the same as in the tuff to the east. The plagioclase and quartz crystals range about the same size, 1/8 to 3 mm; ½ mm is the average. Both are corroded and embayed; quartz is slightly more corroded than the plagioclase. The plagioclase has delicate oscillatory zoning and polysynthetic twinning; its composition ranges from An_{35-57}. The augite is altered in part to chlorite, a brown uralite(?), and magnetite. The pumice fragments are up to about ½ inch in length, generally are lighter colored than the vitric matrix, and contain plagioclase and fewer number of quartz crystals. The lithic fragments are smaller and consist, in order of abundance, of grayish-olive-green pilotaxitic andesite, grayish-black porphyritic vitrophyres and light-olive-

PLATE 17

Stampede Tuff

A. Typical crystal-vitric tuff from zone 2 along the west side of Lake Keechelus. Abundant dark-colored pumice and lithic fragments are present although they compose less than 10 percent of the rock.

B. Crystal-vitric tuff from zone 2 along Gale Creek in the NW¼SE¼SE¼ sec. 32, T. 21 N., R. 9 E. Rock is yellowish gray. Large pumice fragment occurs in the center of the specimen. Crystals and pumice and lithic fragments are less abundant than in specimen A above. Compare with specimen in plate 18A.



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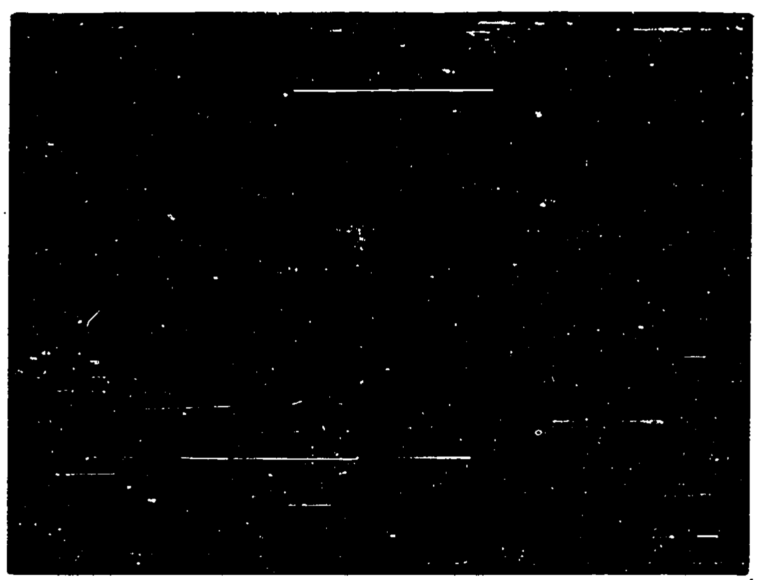


B

PLATE 17

gray mosaic of very fine-grained quartz and feldspar, probably of former feldspathic sandstone. Carbonaceous fragments are locally present. The crystals and fragments are embedded in a vitroclastic matrix, composed almost entirely of weakly compressed shards, which have been extensively altered and devitrified. The tuff has been only partially welded. The rock is very similar in appearance to specimens shown in Smith (1960; pls. 21B and 21 G). The devitrification is probably due to both vapor-phase crystallization and low-grade regional metamorphism (zeolitization). The most intensely altered rock is the grayish-blue-green tuff in unit 4, exposed in the quarry on the east shore of Lake Keechelus (ST 6).

The pumice crystal-vitric tuff-breccia composes about 25 per cent of the formation. It is the most diagnostic rock of the formation and has aided in correlating the various stratigraphic sections (pl. 19). The rock is lithologically similar to the tuff except for the abundance of the pumice fragments (pl. 18B; spec. 18). They are rounded to slightly flattened, range up to 5 inches in diameter but average about one inch. They comprise 10 to 15 per cent of the rock.

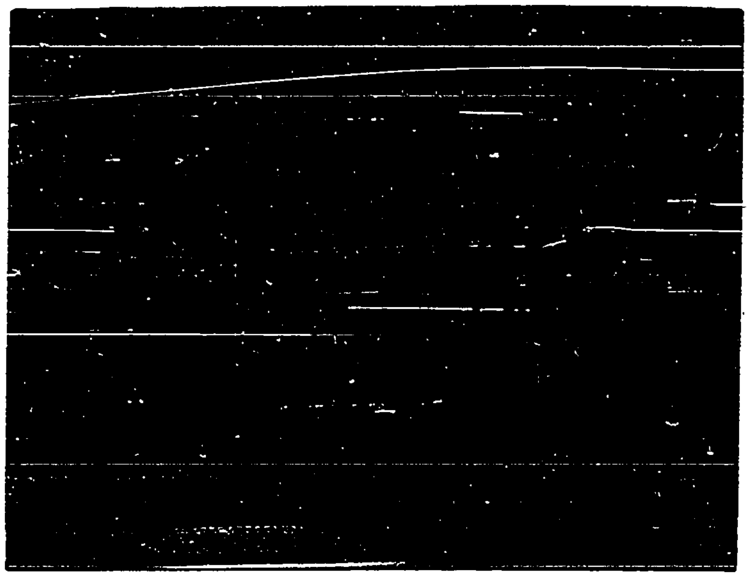
Lithic tuff-breccia composes the remaining rock of the formation. This rock is most extensive at the base of two units of the formation along the east shore of Lake Keechelus (pl. 19). It forms two well-defined zones, 20 and 80 feet thick. The upper breccia zone consists of abundant fragments, up to 2 feet in diameter, but

PLATE 18

Stampede Tuff

A. Crystal-vitric tuff from zone 2 along the North Fork of Taylor Creek. Rock is greenish gray. Few dark fragments are lithic. Large fragments are pumice. Except for color, rock is very similar to tuff in plate 17B.

B. Pumice-crystal tuff-breccia from zone 3 along the west side of Lake Keechelus. Large light-colored fragments are pumice, some of which are porphyritic. Small dark fragments are vitrophyres. Photograph is taken looking down upon plane of eutaxitic layering.



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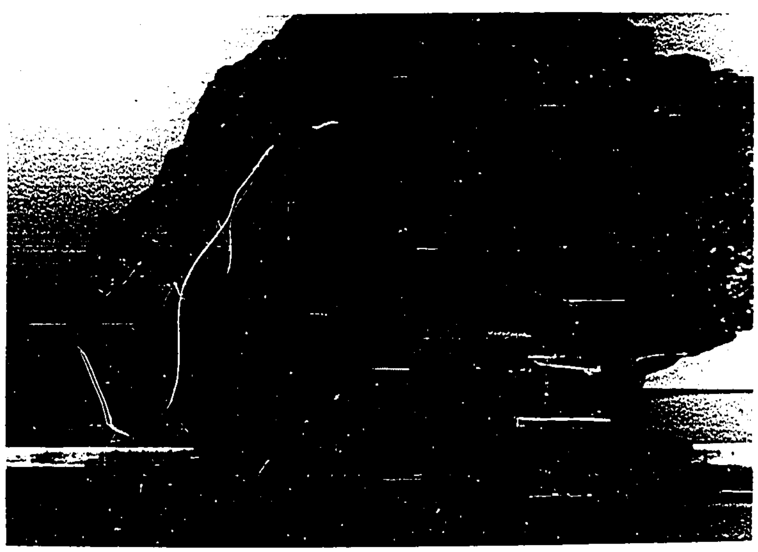


B

PLATE 18

averaging one inch, subangular to rounded, of various shades of greenish gray and brownish gray. Most of the fragments are andesite porphyry. The lithic fragments are present up to 35 percent. Altered porphyritic pumice is a minor constituent. The fragments are embedded in a highly altered dark-greenish-gray groundmass. West of Stampede Pass, at the type section, the breccia forms a dark-greenish-gray basal zone up to 20 feet thick, which is composed of fewer number of lithic and more pumice fragments. Farther west the lithic breccia is not distinguishable.

A darker-colored crystal-vitric tuff occupies the vent zone along the east shore of Lake Keechelus (ST 3). The rock is massive, very well indurated, and from all outward appearances is an intrusive dacite porphyry. It is medium dark gray. The pumice fragments appear to be greenish-black autoliths. Microscopic study, however, reveals that this is a tuff (spec. 19). It is composed of about 20 percent quartz crystals, 15 percent plagioclase (An_{28-38}) and one percent each augite and magnetite. Lithic and pumice fragments, less than ½ inch in size, compose about 7 percent of the rock. The rest is a cryptocrystalline groundmass in which the former vitroclastic texture is discernible. The shards are well compressed and molded against the crystals. The pumice fragments are flattened but their orientation with respect to the wall rock contacts and the overlying tuff unit is not known. The rock is highly welded.

Goodspeed and Coombs (1937) examined outcrops of the Stampede Tuff along the east shore of Lake Keechelus which contained large irregular dark-brown fragments in a greenish-gray groundmass of typical fragmental volcanic rock. The fragments occurred as either coarse angular breccia, as lacy-like fragments, or as long tabular dike-like masses. They were very fine-grained, had a clastic texture, and consisted of quartz, feldspar, hematite and chlorite. The plagioclases of the greenish-gray groundmass were interpreted as prophyroblasts because they had gradational borders, many inclusions and filled veinlets. Their composition was An_{25}. The quartz crystals in the groundmass had a vermicular-like texture (possibly corrosion and embayment). They concluded that the dark-brown clastic material had been converted into the grayish-green rock by recrystallization replacement due largely to emanations from a magmatic source at depth. Unfortunately the outcrops they studied were excavated in 1957 during the widening of U.S. Highway 10. Although he did not examine every part of the outcrops along the lake, the present writer did not find rock which completely fits the description of Goodspeed and Coombs. Their outcrop possibly was located along the periphery of the vent zone or was a part of the lithic tuff-breccia at the bases of zones 2 and 3. The brown clastic material is probably fragments of sandstone which underlies the amygdaloidal porphyritic flows of the "Naches Formation" exposed along the highway just north of the vent. The presence of abundant pumice fragments in both the vent rock and the stratified tuff are, in the opinion of the writer, undoubted criteria for pyroclastic origin. Their (Goodspeed and Coombs, 1937, p. 21) chemical analysis of the grayish-green groundmass (dacite crystal-vitric or pumice crystal-vitric tuff-breccia) is as follows:

SiO_2	50.55%
Al_2O_3	16.80
Fe_2O_3	2.42
FeO	5.53
Mno	tr
Mgo	1.95
CaO	3.55
Na_2O	4.92
K_2O	.58
TiO_2	.68
H_2O + 105° C.	2.30
H_2O - 105° C.	.55
P_2O_5	.14
	99.97%

Stratigraphic sections.--Some of the distinctive features of the sections shown in plate 19 and at other localities are described below, starting with the easternmost outcrops at Lake Keechelus. Zones 1 through 4 correspond to the subdivisions exposed in the cuts along U.S. Highway 10 along the east shore of Lake Keechelus. The east side of Lake Keechelus, Stampede Pass and Green Canyon localities provide the most complete sections. Criteria for distinguishing the subdivisions within the formation

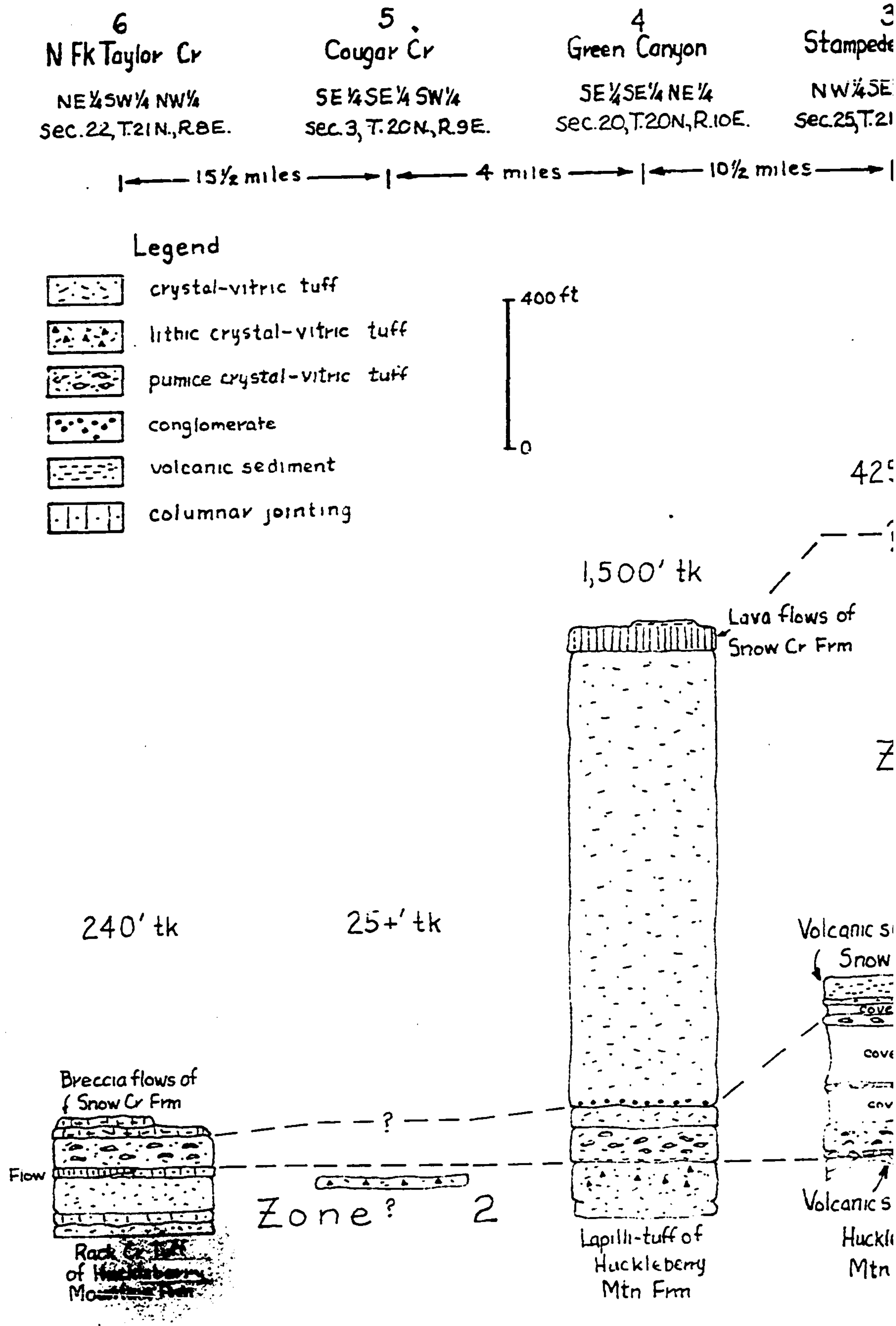
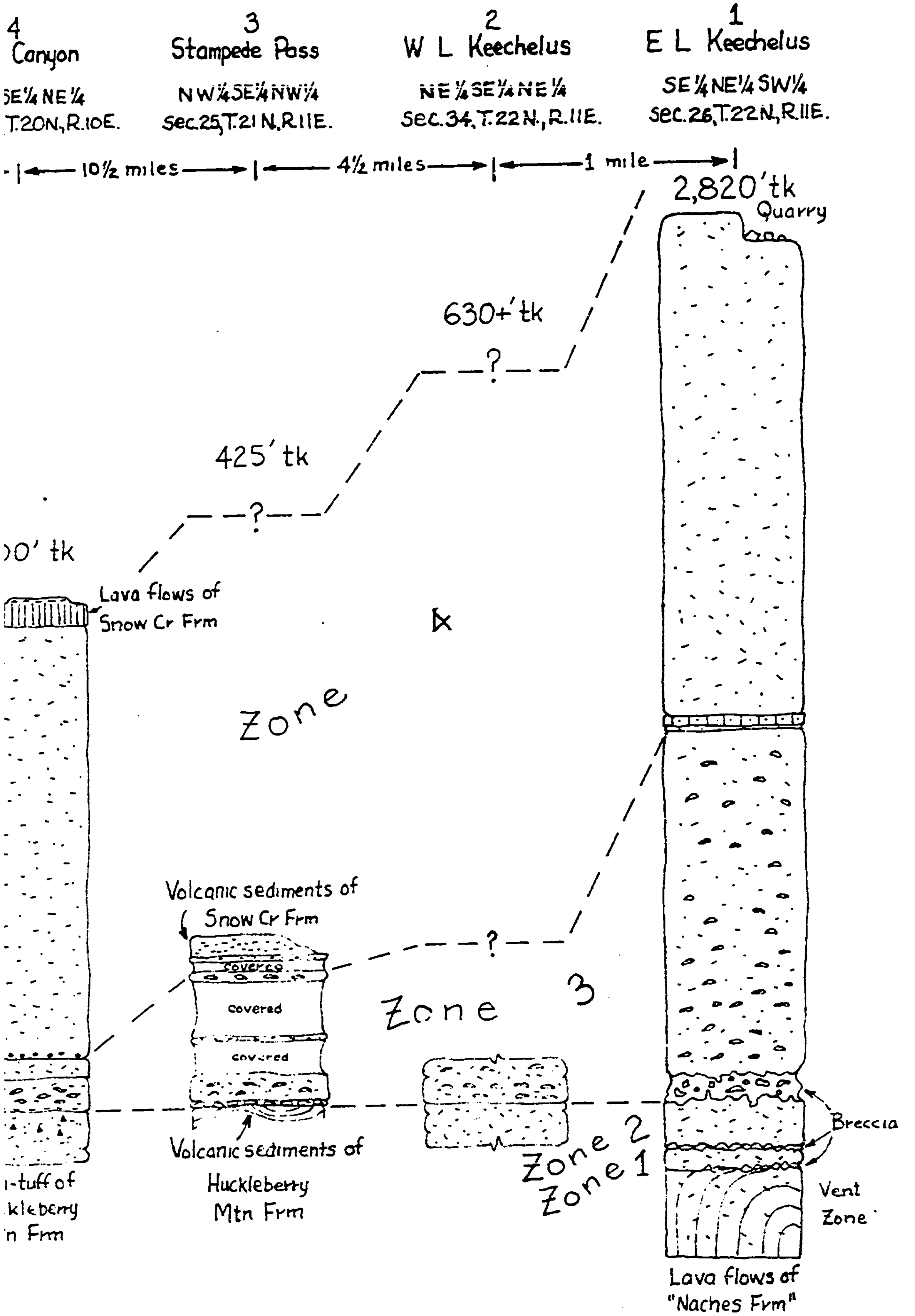


Plate 19 Generalized columnar se



zed columnar sections of the Stampede Tuff have been described in the discussion on Rock Types. The formation is a composite ignimbrite.

Along the east side of Lake Keechelus (column 1 in pl. 19) the lowest part of the exposure is the vent zone. This zone is about 250 feet wide. The north side of the zone is marked by a brecciated zone 10-25 feet wide of angular fragments of predominantly tuff and lesser amounts of the amygdaloidal porphyritic flow rock, which are a part of the lava flows of the "Naches Formation" exposed along the highway just north of the contact. The zone trends N 72° E into the cut and is vertical. Some fault movement subsequent to the brecciation has taken place but incorporation of tuff and flow rock fragments in a tuffaceous matrix and thermal metamorphism of the north wall rock, which diminishes in effect northward, suggests strongly that the brecciation occurred during the extrusive process, injecting the tuff into the brecciated wall rock. Study of aerial photographs indicates that the vent zone extends eastward about 5,000 feet from the highway. Westward it extends under Lake Keechelus. To the south the massive, regularly jointed vent rock is overlain apparently unconformably by tuff of zone 1 with a eutaxitic layering aligned N 65° W and dipping W 40° SW. The tuff has a slabby jointing which serves to distinguish it from the underlying vent rock. The contact is marked by a discontinuous zone of lithic breccia up to 2 feet in thickness. Further examination of the vent zone will be necessary to determine the relationships between the compaction and orientation of the pumice fragments and the wall rock and overlying stratified tuff unit. At present the known relations suggest that the vent was the source of a tuff which preceded deposition of the tuff composing zone 1. The tuff of zone 1 may have been derived from the vent zone at a point eastward or westward from the outcrop at the highway. This possibility should be kept in mind when reexamining the other sections and attempting to correlate zone 1 here with a lower zone elsewhere.

Zone 3 unconformably overlies a "hill" of tuff, lithologically similar and correlated with zone 2, about 200 feet south of the snowshed. The rock of zone 2 probably has been elevated to the level of the highway by movement along a fault trending N 65° E and dipping 70° NW exposed in the northern part of the exposed "hill."

The exposures of the middle part of zone 4 along the highway are weathered and iron-oxide stained. The upper part is massive, very well indurated and has an extremely well-developed joint system. A prominent joint dips steeply westward toward the lake. During widening of the highway in October 1957 undercutting of the rock lying above the joint planes was the primary cause of the landslide. The rock of the upper part is well exposed in the quarry just to the southeast of the landslide (ST 6). This tuff is not typical of the formation because of its intense alteration, which is probably due to hydrothermal solutions arising along a fault underlying Lake Keechelus (see discussion of Structure).

The stratigraphic relationships along the east shore of Lake Keechelus may be considerably more complex than shown in plate 19. A fault has been recognized about 200 feet south of the snowshed but others may exist, so the section may be in part repeated. This area has the greatest preserved section of the formation. The preservation may be due in part to subsidence of the area. Study of aerial photographs shows that the zones are overlapping; that is, zone 4 does not directly overlie zone 1. Zones 1 through 4 could possibly have been derived from that part of the vent which now is submerged by the lake. Answers to these possibilities must await detailed examinations of all the outcrops.

Column 2 (pl. 19) located on the west of Lake Keechelus (ST 7), is incompletely measured. Further field work is necessary here in order to work out the stratigraphic succession at Lake Keechelus--to determine the relationships of the units and the presence of additional units. The pumice crystal-vitric tuff-breccia zone lies directly across the lake from its exposures on the east so the correlation of this unit is fairly reliable.

Sporadic exposures west of the lake indicate that the tuff extends along the top of Roaring Ridge and along the bases of Tinkham and Abiel Peaks. The basal contact of the tuff is not exposed in these areas. The most complete section is exposed on the east side of Tinkham Peak where the tuff has amaximum thickness of 80 feet. Erosion may have removed most of the tuff before deposition of the Snow Creek Formation. The explosive force of the extrusion may have directed most of the ash southward of here so that only a thin layer of ash was deposited. A strong wind at the time of eruption may also have had the same effect. Or, the ash may have slid downslope before sufficient amounts of it had accumulated, insulated and welded. The mechanism envisions is similar to the avalanche of snow when it accumulates rapidly on steep slopes.

Southwest of the lake the tuff is exposed on the north side of Meadow Creek and along the Chicago, Milwaukee, Saint Paul and Pacific Railroad (ST 8). At the latter locality about 300 feet of massive crystal-vitric tuff is tentatively correlated with zone 2. Neither the top nor the bottom is exposed.

A section of part of the zones of the tuff is exposed west of Stampede Pass at the type locality (ST 1) and is shown in column 3 of plate 19 (see section in Appendix A). The same zones exposed here are believed to extend southwestward along Sunday Creek, beyond the west portal of the Stampede Tunnel and westward to Snow Creek. At Sunday Creek near its junction with Borup Creek the section has thinned to about 40 feet.

The Green Canyon locality (column 4 in pl. 19; ST 9) excellent exposure of the tuff is found. The pumice crystal-vitric tuff-breccia of zone 3 overlies about 3 feet of very well-bedded coarse-grained volcanic sandstone, which in turn overlies about 100 feet of lithic crystal lapilli-tuff of zone 2. Zone 4 overlies zone 3 with a well-exposed disconformity. The base of zone 4 is marked by a 10-foot bed of volcanic conglomerate consisting predominantly of cobbles of light-gray quartz aphanite porphyry.

About 15 feet of a pale green dacite crystal-vitric tuff was noted along a stream (ST 10) east of Rooster Comb. The rock is very similar to the Stampede Tuff so it is tentatively correlated with it. However, the exposure is so poor that the writer was unable to determine its stratigraphic relationships. Lithic-crystal-vitric tuff similar to that in zone 2 at the Green Canyon locality occurs along Smay Creek about 100 yards north of the bridge (ST 11) and along the U.S. Forest Service road between Cougar and Sylvester Creeks (ST 12). An incomplete section exposed at the Cougar Creek locality is shown as column 5 in plate 19.

Massive, well-indurated, crudely columnar-jointed crystal-vitric tuff is exposed near the bridge across the Green River (ST 13), and along the Gale Creek road (ST 14). The exposures are 40 and 200 feet thick respectively. These outcrops represent the upper part of zone 2 exposed at the Green Canyon locality.

The westernmost locality is shown as column 6 in plate 19 (ST 4). A crystal-vitric tuff with columnar jointing is lithologically similar to zone 2 described above and is correlated with the section at Green Canyon. The zone is overlain here by a valley-fill lava flow, up to 280 feet thick, of grayish-black fine-grained andesite with well-developed blocky jointing. The flow is best exposed along the road about one mile west (ST 14) and can be traced eastward to the west side of the valley of the North Fork of Taylor Creek where it thins out and is not present in the section measured on the east side of the creek. The flow is overlain by massive grayish-blue-green pumice crystal tuff-breccia of zone 3, which extends across the creek, thereby enabling correlation of this section with that near Green Canyon.

Contact relations.--The Stampede Tuff unconformably overlies the "Naches Formation" to the east and Huckleberry Mountain Formation and Eagle Gorge Andesite to the west. It is conformably overlain by the Snow Creek Formation in the eastern and extreme western parts of the area. In the middle part of the area it has been removed during the erosion interval prior to deposition of the younger Cougar Mountain Formation (see discussion of Cougar Mountain Formation). The contacts of the tuff are well exposed at both sides of Lake Keechelus, Stampede Pass, near Green Canyon and at the North Fork of Taylor Creek. The contact relations at these locations are shown diagrammatically in plate 19.

Folding of the underlying strata had occurred prior to deposition of Stampede Tuff. Evidence of folding is the shallow syncline in the "Naches" strata underlying the tuff along the east shore of Lake Keechelus and the generally steeper dips prevailing in the immediately underlying Huckleberry Mountain strata along Sunday Creek and the North Fork of Taylor Creek. If the flexuring is discounted and the Eagle Gorge Andesite is presumed to have covered the entire area, the relief of the erosion surface upon which the tuff was deposited may have been as much as 4,000 feet. If the thicknesses of the Huckleberry Mountain Formation in the differentially eroded areas are compared, the relief may have been as much as 8,900 feet. This figure, however, does not take into account the amount of erosion prior to deposition of the intervening Eagle Gorge Andesite. Also, this figure seems unlikely inasmuch as the Huckleberry Mountain Formation thins northward along the Cascade crest and along the western foothills. This thinning relationship suggests that the northern part of the map area had been uplifted prior to deposition of the Stampede Tuff and possibly before outpouring of the Eagle Gorge Andesite. Erosion prior to deposition of these units has removed a considerable thickness of strata in the northern part of the area. Taking into account the differences in thickness of the Huckleberry Mountain Formation along the axis of the Lindsay syncline and the probability that the Enumclaw Formation was as much as 1,000 feet thicker to the west, the maximum relief upon the surface underlying the Stampede Tuff is estimated at 2,500 feet.

Age.--No fossils have been found in the Stampede Tuff. Fossils obtained from the conformably overlying Snow Creek Formation suggest that the tuff is no younger than Oligocene. It is considered tentatively as late Eocene to early Oligocene.

Origin.--Separation of the zones of the formation by a sedimentary deposit, erosional unconformity, and lava flow indicate that the Stampede Tuff is a composite ignimbrite. The tuff is incipiently welded suggesting that it was either extruded with an initial low heat content, or ejected high into the atmosphere where it lost most of its heat, or accumulated in thin sheets in which compaction was negligible before it had cooled below the minimum welding temperature. Of the above conditions the first and last ones probably were most important in the formation of this ignimbrite. The vent rock is considerably more welded than the stratified dacite crystal-vitric tuff, but is not as welded as the andesite crystal-vitric tuffs which occur in the Huckleberry Mountain and Snow Creek Formations. It is believed that the lack of intense welding in the vent rock, where the confing pressure would be high, is due to the low heat content of the tuff and its rapid rate of cooling. The extensive devitrification of the stratified tuffs in the formation suggests that they underwent vapor-phase crystallization during their cooling history and were not greatly compacted prior to cooling.

The areal dimensions of the vent zone, the apparently unconformable relations at the vent, and the zoning of the formation suggests that the tuff was extruded from a fissure, from various locations along the fissure at different times. The lithic breccias at the base of the zones are bedded parallel to the eutaxitic layering, indicating that they are probably products of the extrusion and not the result of intrusive brecciation. The interstratification of the breccia zones with the tuff units also indicates that the tuffs were ejected explosively and that the conduit walls were brecciated and the orifice probably widened. The overlapping of the zones, their unequal areal distribution, and their differing lithologies, suggest that they accumulated at separate times under conditions which varied--the direction and angle at which the ash was ejected, the direction of the prevailing wind, and the volume of each eruption. The rather wide distribution of the tuff and the local varying thicknesses of the deposits further suggest that the ash blanketed the landscape rather than flowed along depressions; although there may have been local areas in which the ash flowed from topographic highs into depressions and accumulated.

Snow Creek Formation.

Definition and type section.--A thick section of interstratified fine tuff-breccia and lapilli-breccia, volcanic sediment, thin lava and breccia flows and subordinate amounts of tuff conformably overlies the Stampede Tuff and constitutes the highest stratigraphic unit of the Keechelus Volcanic Group. The section is named herein the Snow Creek Formation for its extensive outcrop in the drainage basin of Snow Creek in the east-central part of the area.

The type section of the Snow Creek Formation is designated as the exposure along the U.S. Forest Service road about 1¼ miles west of Stampede Pass (SC 1). Here volcanic sediment, a mudflow tuff-breccia and the Sunday Creek Tuff Member are well exposed. The section is described in Appendix A. Only the lower part of the formation is exposed in this section. The basal contact with the Stampede Tuff is exposed along the railroad below the road and to the north at the type section of the Stampede Tuff (ST 1). The upper part of the formation, consisting predominantly of volcanic sediment and tuff-breccia, is exposed discontinuously along the roads in the drainage basin of Snow Creek to the west. The contact with the overlying Cougar Mountain Formation is exposed farther to the west (see discussion of contact relations).

The Snow Creek Formation in the northwestern part of the map area (see discussion of distribution) consists predominantly of lava and breccia flows. A reference section in the western area is designated as the exposures along the road south of the North Fork of Taylor Creek (SC 2). The flows and the contact with the underlying Stampede Tuff (ST 4) are well exposed. The contact with the Cougar Mountain Formation is approximately located along the road topographically higher and to the east.

Distribution and thickness.--The formation occurs largely in the trough of the Lindsay syncline which extends through the middle of the map area. The formation has a limited distribution in the western part of the Lindsay syncline. It occurs in the area between the North and Middle Forks of Taylor Creek in the central part of T. 22 N., R. 8 E. Lava flows of the formation, resting upon Stampede Tuff, are sporadically exposed along the trough of the Green River syncline along the Green River in the eastern and western parts of T. 20 N., Rs. 9 and 10 E., respectively. The formation is most extensive in the area along the Cascade crest between Tinkham Peak and Stampede Pass. North of Stampede Pass the strata are structurally complicated. They are intensely contact metamorphosed in the area south of Tinkham Peak and west of the South Fork of the Cedar River.

At least 3,600 feet of strata, composing the formation, are exposed along the axis of the Lindsay syncline in the eastern part of the area, 4,800 feet along the syncline to the west, and more than 2,400 feet are exposed in the north face and south slope of Thinkham Peak.

Petrography and stratigraphic sections.--The Snow Creek Formation consists of about 35 percent each tuff-breccia (most of which is lapilli-breccia) and volcanic sediments, about

25 percent lava and breccia flows and about 5 percent tuff. The lava and breccia flows are confined largely to the western area of exposure and compose almost the entire section exposed there. They range up to 300 feet thick but average 30-40 feet. They are commonly platy jointed, range in color from medium dark gray to grayish black and weather to a light to moderate brown. Texturally the rock is a very fine-grained to prophyritic pyroxene andesite (spec. 20). The porphyritic type occurs generally in the upper part of the section. The phenocrysts range up to 20 percent of the rock and consist entirely of plagioclase. The plagioclase occurs as stubby to prismatic crystals, which average ½ mm but range up to 2 mm in size, has oscillatory and patchy zoning, polysynthetic twinning, abundant inclusions of very fine-grained anhedral augite and brown glass, and has a composition of An_{32-67}. The texture of the groundmass varies from trachytic, pilotaxitic to intergranular. The trachytic rocks contain up to 65 percent brown glass and occur predominantly in the lower part of the section. Plagioclase constitutes 20-70 percent, augite and possibly a little hypersthene constitute 10-40 percent, magnetite 2-7 per cent, and a brown unidentified mineraloid 1-5 percent of all the flow rocks.

A few of the lava flows are highly amygdaloidal. One exposed at the head of Rack Creek (SC 3) contains zeolite-filled amygdules as large as one inch in size.

The lava flow exposed in the quarry along the Green River east of Nagrom (SC 4) is at least 40 feet thick. It has a crude wavy columnar and irregular platy jointing. The rock is a grayish-black pyroxene andesite porphyry. The phenocrysts constitute about 30 percent of the rock. They include about 20 percent plagioclase, 7 percent hypersthene and 3 percent augite. The plagioclase occurs as stubby prismatic crystals which average 1 mm but range up to 5 mm in length, has oscillatory and patchy zoning, polysynthetic twinning, and has a composition of An_{50-75}. The pyroxenes are anhedral and smaller than the plagioclase. Augite is commonly coarser grained than hypersthene. Some of the hypersthene crystals have a jacket of granular augite. The groundmass is intergranular, consisting of plagioclase laths, granular magnetite and a lesser amount of pyroxene, and a brown unidentified mineraloid. Except for its color, this rock is lithologically similar to the lava flow rock of the overlying Cougar Mountain Formation and possibly is a basal flow of that formation. A similar and possibly equivalent lava flow overlies the Stampede Tuff south of Green Canyon.

Lapilli-breccia, volcanic sediment, and tuff predominate in the eastern part of the area. The fragments are predominantly pumice. The breccia is thin to thick bedded and commonly weathers to form a slabby jointing. The breccia is intimately interstratified with volcanic sediment. The sediment is medium to thin bedded, locally well indurated, and consists largely of lapilli-tuff to fine volcanic sandstone (see pl. 7B).

The tuff is predominantly andesite vitric tuff but varies in percentage of lithic, pumice and crystal constituents. A tuff associated with a mudflow in the drainage basin of East Snow Creek (SC 5), is shown in plate 9.

The most extensive section of the fragmental rocks is exposed at Tinkham Peak but here contact metamorphism of the Snoqualmie batholith has obscured some of their primary volcanic features. An excellent exposure occurs at the type section (SC 1).

Sunday Creek Tuff Member.--An andesite crystal-vitric tuff with intensely welded zones occurs in the lower part of the Snow Creek Formation. This tuff is well exposed at the type section (SC 1). The tuff is essentially a compound cooling unit marked by two distinctive densely welded (vitrophyre) zones. The vitrophyre is illustrated in plate 10A. It is an andesite vitric tuff, containing up to 10 percent very fine-grained crystals of plagioclase (An_{36-56}), augite and magnetite and 3 percent lithic and pumice fragments (spec. 21). The vitrophyre zones are separated by partially welded crystal-vitric tuff, which contains about 15 percent crystals of plagioclase, augite, quartz and biotite (spec. 22). It contains about 5 percent lithic and pumice fragments. The entire unit has excellent eutaxitic layering. The irregularity of the topography buried by the tuff is well shown by the outcrop pattern of the upper vitrophyre zone. The lower vitrophyre appears to die out to the north.

The Sunday Creek Tuff has a maximum thickness of about 80 feet at the above location. The upper vitrophyre zone is exposed farther to the west along the road. The tuff unit is also exposed in a small quarry along the Bonneville Power Administration power line right-of-way between the road and the railroad (SC 6). The unit can be traced about 1,500 feet northward from its type exposure along the road. Considerable float of the vitrophyre was noted in Dandy Creek (SC 7). The northernmost exposure of the tuff is along Meadow Creek (SC 8) and the Meadow Creek road (SC 9). Here the tuff is exposed intermittently for a distance of 110 feet. The vitrophyre zone is not present. West of Stampede Pass it lies about 920 feet above and at Meadow Creek about 860 feet above the exposed top of the Stampede Tuff. Exposures of the vitrophyre zone in the area west of the pass suggest that the zone is a lens and that the tuff may be largely a valley-fill ash deposit or, in a strict sense, a true "ash flow." Further field work is necessary to trace this tuff and to determine the extent of the vitrophyre zones and their relationship to the enclosing less welded tuff.

In the fall of 1962 a logging road was under construction strating from the road crossing at the Chicago, Milwaukee, Saint Paul and Pacific Railroad in the center of sec. 22, T. 21 N., R. 12 E., and extending westward on the north side of the Cascade crest into the headwaters of Dandy Creek. This road should cross the tuff and the Dandy Pass fault zone. Another road is scheduled for construction in the very near future along the south side of Lost Lake in secs. 3 and 4, T. 21 N., R. 11 E. This road should also cross the stratigraphic interval in which the Sunday Creek Tuff lies.

Exposures upstream along Meadow Creek indicate that the Sunday Creek Tuff is overlain in this area by several crystal-vitric tuffs. None of these, however, have been traced outside the Meadow Creek drainage basin.

<u>Contact relations</u>.--The Snow Creek Formation conformably overlies the Stampede Tuff. The contacts, however, are generally not well exposed. If the Stampede Tuff did not underlie this formation it would be impossible to distinguish the rocks from lithologically similar strata of the underlying Huckleberry Mountain Formation, especially in the eastern part of the map area. Along the northeastern ridge of Tinkham Peak (SC 10) the base of the Snow Creek Formation consists of a very thick boulder lithic tuff-breccia which contains abundant flow-layered aphanite flow rock fragments. West of Stampede Pass in the headwaters basin of Sunday Creek (ST 2), the top of the Stampede Tuff grades upward into 6 feet of grayish-green coarse-grained lithic volcanic sandstone, which is in turn overlain by about 120 feet of tuff-breccia. Along Sunday Creek near its junction with Borup Creek (SC 11), the

base of the formation consists of interstratified well-bedded volcanic sediments. Near Green Canyon and in the drainage basin of the North Fork of Taylor Creek the base consists of lava flows which lie with sharp contact atop the Stampede Tuff.

The contacts with the unconformably overlying Cougar Mountain Formation are very poorly exposed except west of Boulder Creek (CM 5). Deeply weathered boulder conglomerate of the Cougar Mountain Formation overlies about 200 feet of extremely well-bedded pale blue to yellowish-gray interstratified epiclastic fine-grained tuff and pumice lapilli-tuff. The contact between the tuff and conglomerate can be located within 20 feet. The tuff contains abundant conifer needles. It is underlain by a pale red amygdaloidal very fine-grained lava flow similar to the flows in the western area of the Snow Creek Formation. The contact along the north side of the East Fork of Smay Creek in the southern part of T. 21 N., R. 10 E., and in the drainage basin of Seattle Creek in secs. 5 and 8, T. 21 N., R. 10 E., is located on study of aerial photographs and topography.

Age.--Plant fossils have been collected from University of Washington localities. They are tentatively identified and listed below:

A 2304

Selaginella sp.

A2305

?*Magnolia* sp.
Castanea orientalis

A2307

conifer needles

The kinds are indicative of an early Tertiary age. In view of the structural and stratigraphic position of the formation, the writer considers the Snow Creek Formation to be probably early Oligocene in age.

Additional leaf fossil localities are listed in Appendix C.

Origin.--The predominance of lava flows in the western area of its outcrop suggests that the flows were derived from sources either in that area or farther to the west. It is equally possible that the source area is presently concealed by the Cougar Mountain Formation. In the eastern part of the area the fragmental rocks of the Snow Creek Formation are much better sorted and stratified than those of the underlying formations. This feature suggests that these rocks were deposited farther from their source. Sources for the flows, epiclastic rocks and tuffs have not been recognized in the map area.

"*Naches Formation*."

Distribution and thickness.--The strata of the Huckleberry Mountain Formation grade eastward into a thick sequence of intercalated epiclastic volcanic rock, basalt to andesite and subordinate rhyolite lava and breccia flows, micaceous arkosic sediment and tuff. Because the strata contain thick intercalations of micaceous arkosic detritus, they are excluded from the Keechelus Volcanic Group and are herein assigned to the "Naches Formation." The formation is considered equivalent to the Enumclaw and part of the Huckleberry Mountain Formations and is essentially a facies change of the principally volcanic-derived rocks to the west.

The formation crops out mainly on the eastern slope of the Cascade Range and occurs in the eastern part of the map area. It conformably overlies the Mount Catherine Tuff and is laterally and vertically transitional with the overlying Huckleberry Mountain Formation (pl. 13).

Smith and Calkins (1906, p. 4-5) originally defined the Naches Formation as "composed of interbedded sandstone and basalt, the sedimentary rock predominating in the lower, and the volcanic in the upper portion. The formation is named for the river in whose basin it is most extensively developed." They mapped it extending along the northeastern side of the upper basin of the Naches River and northward into the area of the upper Yakima River valley. They considered the formation to be equivalent to the Swauk Formation because it includes lithologically similar rock and unconformably overlies pre-Tertiary crystalline rocks. They added that the basal contact is locally obscured by the Kachess Rhyolite, and the upper surface, where not in contact with Kachess, is unconformably overlain by the Keechelus Andesitic Series. Unfortunately they did not indicate where the Keechelus rocks lay unconformably upon the Naches strata. They considered the formation to be about 4,000 feet thick in the west and to thin toward the northeast. They regarded it to be Eocene.

Stout (1959, p. 66-67) redefined the "Naches Formation" to include rocks of the Teanaway Basalt, Kachess Rhyolite, Yakima Basalt, and part of the Keechelus Andesitic Series, mapped by Smith and Calkins, and the Manastash Formation (Smith, 1904). The Keechelus rocks exposed at Cabin Mountain and along the south side of the upper Yakima River valley were assigned to the "Naches Formation" because they are the stratigraphic continuation of the "Naches" rocks to the south. Stout considered the best section to be exposed along relatively inaccessible Bear Creek in the southern part of T. 19 N., R. 13 E., just beyond the southeast corner of the map area (pl. 1). He believed that the formation has a minimum thickness of 8,000 feet. He mapped the formation as lying either upon or in fault contact with pre-Tertiary crystalline rocks, and overlain unconformably by "Keechelus-type" rocks and Yakima Basalt.

Foster (1960) assigned the name "Naches Formation" to the upper part of the strata which Smith and Calkins mapped as the Guye Formation and the lower part of the Keechelus Andesitic Series. In addition he assigned to his "Naches Formation" the rocks which

Smith and Calkins mapped as Teanaway Basalt along the west side of Lake Kachess east of the map area. His "Naches Formation" includes basalt, sedimentary rocks, and rhyolite, similar lithologically to Smith and Calkins' Naches Formation. He estimated the formation to be about 5,000 feet thick. He defined the formation as overlying conformably the Mount Catherine Rhyolite and underlying unconformably his restricted "Keechelus Andesite." Foster attempted to delineate the unconformable contact between the "Naches" and "Keechelus" in the area between Lakes Keechelus and Kachess but his map shows improbable structural relationships which need reexamination.

The present writer recognizes Foster's definition of the "Naches Formation" but is enclosing the name in quotes until such time as it is ascertained that the rocks which Smith and Calkins named as Naches Formation extend northward and constitute the same strata in the Lake Keechelus area. Structurally, the correlation is favorable, but additional field work is necessary in the area east of Blowout Mountain and south of the upper Yakima River area. Stout's map (pl. 2) indicates some of the structural complexity in that area. Aerial photographs of the area reveal some of the best and most easily diagnosed structural features that the writer has seen exposed in the central Cascade Range. Tightly plunging folds can be traced but they are discontinuous suggesting fault relationships. The ridges traverse the bedding and so reveal the major part of the strata in the area. At present the area is accessible only from the trails leading from the ends of the roads west of Blowout Mountain, to the west, and at Quartz Mountain, to the east (pl. 4). In the near future a U.S. Forest Service road will be constructed into the Big Creek drainage basin in T. 19 N., R. 13 E., and will provide convenient access.

In the map area (pl. 1) the "Naches Formation" has a thickness ranging from 3,600 feet to 9,600 feet. A minimum thickness of 3,600 feet is preserved between the Stampede Tuff and the Mount Catherine Tuff, without consideration for any displacement on the Roaring Ridge fault, in the drainage basin of Cold Creek in the southern part of T. 22 N., R. 11 E. At least 5,400 feet of strata of the lower "Naches" are exposed along the southwestern ridge of Kendall Peak, from the top of the Mount Catherine Tuff eastward to the southeastern face of the peak (N 1) about 3¼ miles south of the northeastern corner of the map area. About 9,600 feet of strata are exposed along Rampart Ridge, measured from the top of the Mount Catherine Tuff at Gold Creek (N 2) northeastward to the stratigraphically highest Rampart Ridge Porphyry Flow along the eastern side of the ridge (N 3). Over 3,300 feet of the middle and upper parts of the formation are exposed in the cuts along U.S. Highway 10 southeast of Lake Keechelus (N 4). The formation thickens to the south, based on a comparison of the stratigraphic intervals between the Rampart Ridge flows and the Kendall tuff.

Petrography and stratigraphic sections.--The lithology of the Naches is variable laterally and vertically. The reader is referred to Stout (1959, p. 66-108) for detailed descriptions of the rock types. The Kendall Tuff Member in the middle part and the Rampart Ridge Porphyry Flow and Blowout Mountain Flow Members in the upper part, are described separately below.

The formation is estimated to be composed of about 50 percent lava and breccia flows, 40 percent micaceous arkosic sediment and 10 percent fragmental volcanic rock. In general the formation seems to be richer in micaceous arkosic sediment in the lower part; flows predominate in the upper part. Fragmental volcanic rocks are about equally distributed in the section but increase in volume southward and westward.

A 1,000-2,000 foot section consisting predominantly of epiclastic volcanic rocks, underlies the Stampede Tuff at Roaring Ridge. The section is exposed along U.S. Highway 10 (N 5) near Lake Kachess, and extends southeastward between two fault zones to the Yakima River west of Lake Easton. There it is exposed along the two railroads. The same unit of epiclastic rocks may extend southeastward along the southern slope of Cabin Mountain. Westward the rocks become finer grained and crop out as fine tuff-breccia and volcanic sandstone.

The northern slope of Cabin Mountain is a homocline dipping beneath the Yakima River valley. The homocline is underlain by thick basalt and andesite lava flows. These flows underlie the Rampart Ridge Porphyry Flows and are believed to extend westward from Cabin Mountain, through the headwaters of Cabin Creek, and southward along the Cascade crest to Blowout Mountain where they are well exposed on the ridge northeast of the mountain. On the north side of the upper Yakima River valley these flows are exposed along U.S. Highway 10 (N 4) and extend from there northward along the western flanks of Amabilis and Keechelus Ridges. These flows are well exposed along east shore of Lake Keechelus just north of the vent zone of the Stampede Tuff. The same strata of flows are also well exposed on Rampart Ridge in the area of Laura and Lillian Lakes and in the upper part of Kendall Mountain. They have been down-faulted into juxtaposition with strata of the Guye Formation and intensely contact metamorphosed in the area along the east side of the upper South Fork of the Snoqualmie River along U.S. Highway 10 (N 6).

The micaceous arkosic sediment occurs in most sections between the flows and the tuff-breccia and at the base of the formation. The sediment is fairly well exposed in the areas between Mill and Cold Creeks (N 7), along the ridge southwest of Kendall Peak (N 8), along the Chicago, Milwaukee, Saint Paul and Pacific Railroad (N 9), along U.S. Highway 10 (N 4), at the headwaters of Cole Creek (N 10), along Cabin Creek (N 11), east of Log Creek (N 12), and in the headwaters of Log Creek (N 13). Along Cabin and Cole

Creeks the strata include some impure coal beds and are disharmonically deformed.

Extremely well flow-layered and spherulitic rhyolitic flows are exposed sporadically in the "Naches Formations." They are readily distinguished in outcrop by their pink to pale reddish-brown color. The best exposures are east of Goat Peak (N 14) and atop Cole Butte (N 15). From the latter locality they extend southwestward along the ridge. They are also exposed interstratified with the Rampart Ridge Porphyry Flows atop Rampart Ridge. Altered rhyolite(?) dikes intrude the "Naches Formation" and are extremely well flow-layered. They can easily be mistaken for flows if the contacts are not exposed.

It has already been mentioned in the discussion of the Huckleberry Mountain Formation that an intensely welded black crystal-vitric tuff has been noted on the west slope of Cole Butte (N 16) and is very similar lithologically to the tuff exposed stratigraphically above the Twin Camp Creek Flows. These tuffs may be stratigraphically equivalent.

A stratigraphic section of the "Naches Formation" exposed along U.S. Highway 10 (N 4) is described in Appendix A.

Kendall Tuff Member.--A lithic-pumice-crystal-vitric tuff occurs about the middle of the "Naches Formation" in the area north and east of Lake Keechelus. It was first recognized and is fairly well exposed on the ridge southwest of Kendall Peak, hence the name. Here it is about 550 feet thick, lies about

4,150 feet above Mount Catherine Tuff and about 2,800 feet below the lower flow of the Rampart Ridge Porphyry Flow Member. The unit has not been examined in detail. In general it appears to be richer in pumice fragments toward the base and richer in lithic fragments toward the top. A crystal-vitric tuff occurs at the top. In all outcrops it is highly weathered. It is distinguished from Mount Catherine Tuff by the greater abundance of lithic fragments and from Stampede Tuff by the fewer feldspar crystals. The quartz crystals average about 3 mm in size. The Kendall Tuff has a better developed eutaxitic layering than the Stampede Tuff. The Kendall Tuff is exposed in cuts along the road on the west face of the Rampart Ridge (N 2) and along U.S. Highway 10 southeast of Lake Keechelus (N 17). The tuff has not been traced farther southward. Its stratigraphic position would lie in about the unexposed interval along U.S. Highway 10 (N 4) between the micaceous arkosic sediment to the west, and the underlying tuff-breccia to the east.

Rampart Ridge Porphyry Flow Member.--A diagnostic flow rock (pl. 20A), consisting of abundant asterated laths and scattered stubby prisms of plagioclase in a very fine-grained intergranular groundmass spotted with numerous amygdules of calcite, chlorite and chalcedony, has been noted in float along streams draining Rampart Ridge. Subsequently the flow rocks were found atop Rampart Ridge (N 18). Here the flows are part of a sequence which consists largely of amygdaloidal porphyritic basic andesite and a few rhyolitic flows with well developed flow-layering. Minor amounts of tuff-breccia are present. The sequence is 2,130 feet thick. Three flow units within the sequence constitute the Rampart Ridge Porphyry Flows. The lower unit underlies the basin containing Lillian Lake. It is 160 feet thick. The second unit is 260 feet thick, caps the high point at the southwestern end of the ridge above the lake, and lies 900 feet above the top of the lower unit. The highest unit occurs along the upper eastern slope of Rampart Ridge north of Lillian Lake. It is 260 feet thick, lies 550 feet above the top of the middle unit, and is underlain and overlain by light-colored rhyolitic lava flows.

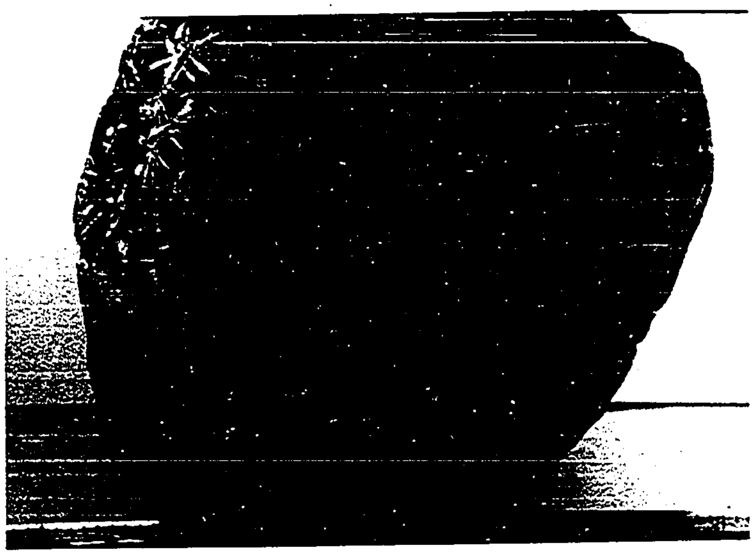
An identical flow rock was noted as float in Burntboot Creek, a tributary of the Middle Fork of the Snoqualmie River, in sec. 15, T. 23 N., R. 11 E. (W. L. Rice, personal communication). Projection of the trend of the flows northward suggests they lie in the area of Mount Thompson. Professor Joseph A. Vance reports that the flows compose the summit of Mount Thompson. Westward the flow rock is exposed in the contact metamorphic zone of the Snoqualmie batholith in cuts along U.S. Highway 10 just south of Lookout Point (N 19). Southward the flows crop out along the roads at the south end of Keechelus Ridge (N 20). The outcrops here are believed to be a part of the lower unit. Farther southward the flows are believed to underlie the well-fractured

Plate 20

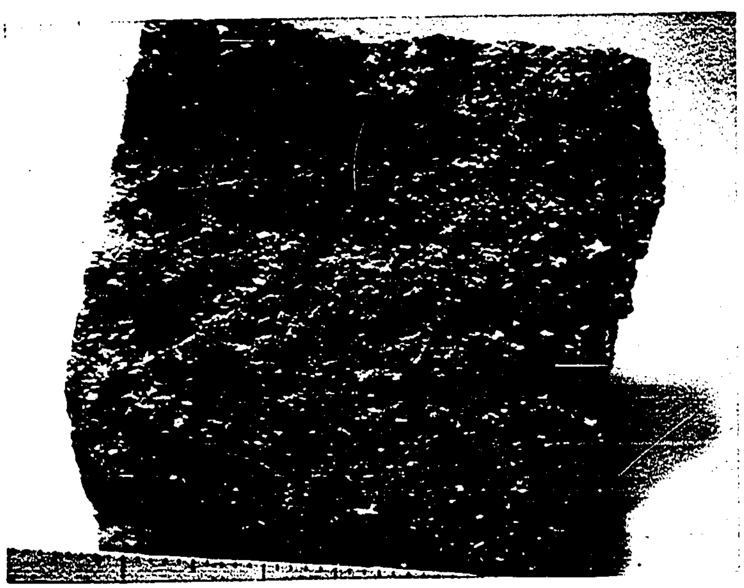
Lava flow rocks of "Naches" and Cougar Mountain Formation

A. Rampart Ridge Porphyry Flow rock from Rampart Ridge.

B. Typical flow rock of the Cougar Mountain Formation. Rock is light gray and has incipient flow layering. White specks are plagioclase phenocrysts; dark are pyroxene. This sample is from upper flows along the North Fork of the Green River in the NW¼NW¼NW¼ sec. 1, T. 21 N., R. 8 E. Compare with Keechelus flow rock in plate 15B.



A



B

PLATE 20

amygdaloidal flows exposed along the east side of U.S. Highway 10 at the Lake Kachess overpass (N 21). The rock crops out along the Chicago, Milwaukee, Saint Paul and Pacific Railroad (N 22) east of Stampede Pass, and along U.S. Highway 10 (N 4; see stratigraphic section in Appendix A). The outcrops at these localities are believed to be part of the lower unit. The sequence is present along the Northern Pacific Railroad to the south (N 23; spec. 23). The flows have not been traced south of this location.

Blowout Mountain Flow Member.--The Blowout Mountain Flow, mentioned in the description of the Huckleberry Mountain Formation, is exposed southeast of Blowout Mountain (HM 36). The flow rock is much finer grained but is identical to the Rampart Ridge Porphyry Flows. It consists of medium-grained laths to stubby prisms of plagioclase and fewer, finer grains of anhedral augite phenocrysts in an intergranular groundmass of plagioclase laths, granular magnetite and abundant augite, and brown uralite(?) (spec. 24). The plagioclase phenocrysts (An_{52-75}) comprise about 15 percent of the rock and tend to be formed in clusters although not as characteristically as the Rampart Ridge Porphyry Flows. The augite phenocrysts constitute about 2 percent of the rock. About 3 percent of the rock is amygdules of brown uralite(?) with calcite rims. The flow has not been traced northward. The nearest occurrence of similar rock is characteristic Rampart Ridge Porphyry Flows along the Northern Pacific Railroad to the north. East of

Blowout Mountain the flow can be traced easily on aerial photographs. The flow is shown on the map (pl. 1), extending northward to Big Creek and swinging eastward on the north side of the creek below the ridge with the Big Creek triangulation point. Lava flows, very similar to the flows overlying the Rampart Ridge Flow, along the Northern Pacific Railroad occur above this unit in the ridge and extend westward to the head of Big Creek and southward. Smith and Calkins (1906, p. 9) noted a fresh "labradorite porphyry" in association with sediments of their Naches Formation in the Big Creek drainage basin. The writer suspects that the Blowout Mountain Flow is the same rock and becomes more distinctly porphyritic, similar to the Rampart Ridge porphyry flows, a short distance to the east. Further field examination to trace the extent of this unusual flow rock is warranted.

The linear extent of outcrop of the Rampart Ridge porphyry flows is about 24 miles, from Burntboot Creek in the north to Blowout Mountain in the south, and about 8 miles from the outcrops at Lookout Point eastward to a point due north of Blowout Mountain. East of Rampart Ridge the lower part of the "Naches Formation" has been uplifted along a north-trending reverse fault and the flows are not present. Ellis (1959, p. 44-52) did not report observing a similar flow rock in his "Naches Formation" in T. 23 N., Rs. 12 and 13 E. The decreasing grain size of the plagioclase phenocrysts toward the south suggests that the flows were extruded in the north and flowed southward.

Contact relations.--The contacts of the "Naches Formation" are not well exposed. The base lies outside the map area except in the area between Mill and Cold Creeks (MC 7) where the Mount Catherine Tuff crops out. Along Mill Creek basal sandstone of the formation is intruded by a felsite porphyry dike. At least a 960-foot section of micaceous arkosic sediment lies stratigraphically above the contact and is exposed along Mill Creek. The top is herein defined as the top of the Rampart Ridge Porphyry Flows in the upper Yakima River area and the Blowout Mountain Flow in the southeastern corner of the map area. At the base of Abiel and Tinkham Peaks, along Roaring Ridge, and at Lake Keechelus the "Naches Formation" is overlain unconformably by the Stampede Tuff. At Abiel and Tinkham Peaks the Stampede Tuff overlies crystal tuff and pebble lithic tuff-breccia. The contacts are not exposed. At Roaring Ridge (N 24) a dark greenish-gray flow-layered aphanite porphyry flow underlies the Stampede Tuff. Westward the Stampede Tuff caps the sheer cliff on the north side of the ridge. Eastward the aphanite porphyry flow is underlain by pumice lapilli-tuff which forms the top of the fairly thick sequence of fragmental volcanic rocks which occupy the lower to middle part of the "Naches Formation." North of the vent zone of the Stampede Tuff along the east side of Lake Keechelus the uppermost "Naches" consists of contact metamorphosed amygdaloidal porphyritic flows which are a part of the flow sequence immediately underlying the

Rampart Ridge Porphyry Flows. Along the west side of Lake Keechelus the upper part of the "Naches Formation" consists of pumice tuff-breccia and andesite porphyry lava and breccia flows. Southwest of Lake Keechelus the contact is not exposed (see discussion of Stampede Tuff).

Age and correlation.--Smith and Calkins (1906, p. 4-5) considered the Naches Formation to be Eocene basedon the identification of fossil plants by F. H. Knowlton. They also considered the formation equivalent to the Swauk Formation because of similar lithology and stratigraphic relationships. The Swauk Formation, however, is not known to contain intercalated volcanic rocks (Ellis, 1959, p. 18-29; Stout, 1959, p. 87; Hammond, 1961).

Stout (1959, p. 83-94) aptly summarized the ages and correlations previously determined for the strata assigned to the "Naches Formation." In addition he found fossil leaves which were determined to be probable middle Eocene by R. W. Chaney of the University of California and of definite Eocene age by M. B. Pabst of Western Washington College. In conclusion Stout believed that the "Naches Formation" is Eocene and possibly is young as Oligocene.

Foster (1960, p. 116) considered tentatively the "Naches Formation" to be Eocene.

Waters (1961, p. 52, 56) considered the "Naches Formation" to be mainly upper Eocene and equivalent to the Ohanapecosh Formation of Fiske (1960).

Plant fossils were collected from the "Naches Formation" at the following University of Washington localities. They are tentatively identified as:

A2308

?*Selaginella* sp.

A2309

?*Tetracera oregona*

A2310

?*Salix* sp.

Additional leaf fossil localities are listed in Appendix C.

The "Naches Formation" is considered to be late Eocene.

Origin.--The interstratification of volcanic and non-volcanic rocks suggests a complex environment of accumulation. The increase in volcanic constituents southward and westward suggests that the primary source of the volcanic material lay in that direction and that the micaceous arkosic detritus were derived from the north and east. Some volcanic material, however, may have been derived from elsewhere. The lateral change in texture of the Rampart Ridge Porphyry Flows suggests that they have been derived from a northward source.

Cougar Mountain Formation.

Definition and type section.--A thick succession of lava flows, minor amounts of breccia flows, interstratified thick boulder conglomerate and subordinate volcanic sandstone unconformably overlies the Keechelus Volcanic Group in the central part of the map area. It is herein first defined and named the Cougar Mountain Formation. Because this formation is not present in the Snoqualmie Pass quadrangle and, consequently, was not included as a part of the Keechelus Andesitic Series by Smith and Calkins (1906), it is separated from the Keechelus Volcanic Group.

The type section is designated as the southern slope of Cougar Mountain (CM 1). Here the section is generalized as follows:

Upper flows	1,010 feet
Middle boulder conglomerates	1,940 "
Basal flows	260
	3,210 feet

The basal flows are exposed along the road along the West Fork of Smay Creek. The upper flows underlie the crest of Cougar Mountain.

A well-exposed section occurs at Ghost Point, along the north side of the North Fork of the Green River (CM 2), and is designated as a reference section. This section is described in Appendix A. The basal contacts are not exposed at these sections (see discussion of contact relations).

Distribution and thickness.--The Cougar Mountain Formation is confined largely to the trough of the Lindsay syncline which lies to the south. An erosional remnant of similar lava and breccia occurs between Goat Peak and Stampede Pass (CM 3) and is tentatively considered to be a part of the formation. The formation is intruded and contact metamorphosed by the Snoqualmie batholith along the south side of the Cedar River between the south fork of the river and Rex River. In the drainage basin of the South Fork of the Cedar River the formation is intruded by altered pyroxene andesite porphyry, quartz-pyroxene diorite and a satellite of the Snoqualmie batholith. The formation is not known to extend outside the map area.

The formation has a maximum exposed thickness of 5,300 feet in the area of Boulder Creek south of Chester Morse Lake. About 3,210 feet of section is exposed on the southern side of Cougar Mountain, and 4,010 feet crops out at Ghost Point.

Stratigraphic sections.--The formation consists of about two-thirds lava and breccia flows; the remainder is coarse volcanic sediment. The lava flows are readily distinguished from those of the underlying Keechelus flows. They are commonly quite thick, ranging up to 300 feet, and are well jointed. The lower flows tend to be darker colored and have a wavy columnar and platy jointing. These flows are exposed along the south side of the Cedar River valley, southeast of Little Mountain (CM 4), and along the West Fork of Smay Creek (CM 1). A basal flow is well exposed along a recently constructed logging road (CM 5) west of Boulder Creek. The flow shows excellent jointing and overlies thick breccia flows and boulder conglomerates. The lower flows exposed between the North and Middle Forks of Taylor Creek (CM 6), and south of Gale Creek (CM 7) resemble the upper flows. The middle flows, which are exposed only on the northeastern area of the Cougar Mountain Formation, south of Findley Lake (CM 8) northwest of Goat Mountain (CM 9), and in the amphitheater at the head of Goat Creek (CM 10), are a rubbly-weathering flow-breccia. They are well stratified, forming beds 15-25 feet thick, and consist predominantly of fragments of flow rock. Within the beds the breccia locally forms accretionary masses up to 4 feet in diameter. The remnant outlier, east of Goat Peak (CM 3), consists of rock of this type. The upper flows of the formation are generally much thicker, have better columnar jointing, are more resistant and can readily be traced from a distance in the field and on aerial photographs. Several of the flow units are shown on the map.

The upper flows are best exposed along the north side of the North Fork of the Green River from Ghost Point to near Cougar Mountain. They contain equally well-developed columnar and platy jointing. The columns tend to be four-sided, range in diameter from 2-6 feet, pinch and swell slightly, and extend up to heights as much as 80 feet but are commonly 15-20 feet high. The platy jointing ranges in widths of 1-4 inches and is parallel to the commonly well-developed flow-layering which intersects the columnar jointing at an angle less than 90°. Weathering along the joint planes tends to form rhombic-shaped blocks.

The breccia flows are intercalated with the lava flows. They are well exposed in the Goat Creek amphitheater (CM 11), between the North and Middle Forks of the Taylor Creek (CM 12), and along the east side of Rex River (CM 13). Top breccias are exposed on the west side of Boulder Creek (CM 14). Here the breccias are intensely altered and stained with iron oxides. Breccia flows also occur in the type and reference sections.

The volcanic sediments of the Cougar Mountain Formation are of fluvial origin. The boulder conglomerates are massive, and contain a sand matrix and scattered lenses of well-sorted sandstone. At least 90 percent of the clasts are Cougar Mountain flow rock; the remaining are grayish-black fine-grained andesite flow rocks of questionable Keechelus derivation. The sandstone consists predominantly of granular pumice and feldspar crystals. The sandstone lenses and the sand matrix of the conglomerates are light-colored and stained locally by iron oxides. Their light color and susceptibility to weathering enables the conglomerates to be recognized from a distance.

The detailed stratigraphic relationships within the formation are not known. No individual unit has been traced throughout the extent of the formation.

The middle conglomeratic section is shown in plate 1. It extends from the southwest side of Goat Mountain westward along the north side of the Smay Creek drainage basin, through Cougar Mountain and along the North Fork of the Green River. Between the North and Middle Forks of Taylor Creek the conglomerate is considerably thinner. A little conglomerate is exposed west of Boulder Creek (CM 5) and along the roads east of Boulder Creek and north of Rex River. This conglomerate interval may be in the middle of the formation. Very little conglomerate was noted in that part of the formation which lies in the trough of the Green River syncline.

The distribution of the conglomerates indicates that they have filled a former valley which trended west-northwestward south of the present location of the axis of the Lindsay syncline. The width of the valley was about 3 miles. It is uncertain what part of the formation is exposed in the trough of the Green River syncline. Only flow rock is exposed. Conglomerates were found only along the Green River (ST 10) atop Stampede Tuff.

Petrography.--The flow rocks vary in color from olive black to light gray. The lower flows are the darker colored (specs. 25 and 26). The rocks are distinctly porphyritic, containing between 20 and 40 percent phenocrysts which range up to 3 mm in size (see pl. 20B). The plagioclase phenocrysts comprise 15-35 percent of the rock, pyroxenes 5-10 percent. The plagioclase occurs as stubby prismatic crystals, has oscillatory and patchy zoning and is commonly corroded. Their composition is An_{45-65}. The pyroxenes are augite and hypersthene. They tend to be finer grained than plagioclase but locally augite is quite coarse grained, up to 5 mm in size, as exposed in the flows east of Seattle Creek (CM 15) and in the contact metamorphosed breccia flows along the east side of Rex River (CM 16). Augite is slightly more abundant than hypersthene, which commonly has a jacket of very fine-grained anhedral augite. Granular magnetite is present in quantities up to about 2 percent of the rock and commonly is altered to hematite, producing reddish-brown specks on the weathered surface of the rock. The groundmass ranges from merocrystalline to holocrystalline. The glass is brown. The texture of the groundmass varies from felty to pilotaxitic to intergranular.

A pinkish-light-gray friable brecciated flow rock (spec. 27), probably altered by deuteric or fumerolic solutions, is exposed west of Boulder Creek (CM 17). The pyroxenes are replaced by magnetite which has been partially altered to hematite. The groundmass is cloudy with dust of hematite and contains scattered patches of radiating chalcedony(?). All the groundmass pyroxenes have been completely replaced by iron oxides.

The flow rock exposed along the west side of the amphitheater at the head of Goat Creek (CM 18) has been partially altered by contact metamorphism of the pyroxene and hornblende andesite porphyry stock. The rock is dark gray. The plagioclase has been largely altered to calcite, the pyroxenes to chlorite and magnetite, and the groundmass contains abundant magnetite.

Contact relations.--The unconformable basal contact of the Cougar Mountain Formation is not well exposed except locally. The base is fairly well exposed west of Boulder Creek (CM 5). A breccia flow lies at the base of the formation in the area between the North and Middle Forks of Taylor Creek. The basal contact was located by aerial photographic interpretation and topographic evidence in the area between the South Fork of Taylor Creek and the head of the North Fork of the Green River. From the road below Ghost Point the lower breccia flow (see stratigraphic section in Appendix A) extends along the North Fork of the Green River. Similar flow breccia is exposed along the roads south of the North Fork of the Green River (CM 19). A covered interval of about 100 feet separates exposures of lava flow of the Cougar Mountain and Stampede Tuff along the Gale Creek road (CM 20). The contact was not located between these units in the area north of Humphrey (EG 11) but it is presumed that the formations are very near in contact here. East of the bridge across the Green River (CM 21) basal boulder conglomerate overlies outcrops of zone 2 of the Stampede Tuff. Similar conglomerate is exposed along the road between Cougar and Sylvester Creeks (CM 22). A few boulders are of Stampede Tuff and Rack Creek Tuff, but most, as usual, are of Cougar Mountain flow rock. The boulders lie in a clayey sand matrix. The contact is located approximately at the base of the 260-foot unit of flows exposed at the type section (CM 1). Between here and Goat Mountain the contact was located by aerial photographic interpretation. It has been placed below the light-colored conglomerate zone which can be traced on the photographs along the north side of the East Fork of Smay Creek. From Goat Mountain northwestward to Seattle Creek the formation is in contact with intrusions. Dikes of deuterically altered pyroxene and hornblende andesite porphyry have intruded a columnar-jointed flow and richly augite-bearing tuff-breccia and volcanic sediments east of Seattle Creek (CM 15). Along Seattle Creek the base of the formation has been located by topographic and aerial photographic interpretation. The formation has been intruded by the Snoqualmie batholith in the area west of Seattle Creek and south of the Cedar River. The contact is located approximately here because the area is densely forested. A few dikes of quartz diorite similar to the rocks of the batholith intrude the formation near Findley Lake and provide evidence that the Cougar Mountain is older than the Snoqualmie batholith.

The stratigraphic relationships as indicated by the contacts in the area between the Middle Fork of Taylor Creek and Smay Creek reveal that erosion prior to deposition of Cougar Mountain had removed all the Snow Creek Formation and Stampede Tuff and a considerable part of the Huckleberry Mountain Formation. Because folding of the strata has occurred before and after accumulation of Cougar Mountain, it is not possible to estimate the relief underlying the formation. The removal of the underlying strata along the north flank of the Snowshoe Butte anticline is attributed in part to local structural uplift and valley cutting. The valley is now filled by predominantly conglomerates of the middle part of the formation.

Age.--Wood and leaf fossils have been collected from the Cougar Mountain Formation at University of Washington locality A2301. The material has been tentatively identified as:

Metasequoia occidentalis

The unconformable relationship to the underlying Keechelus rocks, the distinctive lithology, and the structural position of the Cougar Mountain Formation indicate that the formation is younger than the Keechelus Volcanic Group. The formation has been intruded by the Snoqualmie granodiorite of middle Miocene age. The formation is tentatively dated as early (?) Miocene.

Additional fossil material may be present in the volcanic sediments exposed in the road cuts in the NW¼ sec. 11, T. 21 N., R. 8 E., and in the SE¼ sec. 28, T. 21 N., R. 9 E., in the drainage basin of the North Fork of the Green River.

Origin.--No source area for the Cougar Mountain lava flows has been located in the map area. A source area may have existed to the north but has become engulfed by the emplacement of the Snoqualmie batholith.

"Ellensburg Formation."--The Naches Pass lava flows (Waters, 1961, p. 50) and volcanic conglomeratic sandstone, similar to the continental sediments of Miocene age (Mullineaux, Gard and Crandell, 1959), exposed between Cyclone and West Twin Creeks (EB 1) north of the White River, are assigned to the "Ellensburg Formation." The volcanic sediments are lithologically similar to the Ellensburg Formation (Smith, 1903, p. 2-3) but the quotation marks should be retained until the stratigraphy of these rocks is delineated in the central Cascade Range.

The Naches Pass lava flows were examined along the east edge of the tableland south of Naches Pass (EB 2). Here the flows form a 350-foot cliff which extends for about 3,500 feet along the east side of the Cascade crest. A flow unit is exposed at the south end of the cliff. The flow has a wavy columnar jointing, in which the columns average about 4 feet in diameter at the base and thin upwards. At this location the columns are inclined to the south. The rock is a black porphyritic andesite (spec. 28). It consists of about 8 percent plagioclase (An_{37-45}) crystals, which are twinned, zoned and contain abundant inclusions of glass; 2 percent hypersthene with jackets of augite; 2 percent granular augite and magnetite. The remaining 88 percent is brown merocrystalline pilotaxitic groundmass, containing abundant feldspar microlites and granular pyroxene and magnetite. The rock is very similar to that described by Waters (1961, p. 50).

A light-gray porphyritic pyroxene andesite with fairly well-developed platy jointing and flow-layering is exposed atop the cliff at its north end. This flow occupies a channel about 50 feet wide and 10 feet deep cut in the underlying black columnar-jointed porphyritic andesite flow.

The contact relations of the main flow were not observed. The extent of the Naches Pass lava flows as shown on the map are based on topographic expression and aerial photographic interpretation. Reconnaissance mapping and study of the aerial photographs indicate that the Naches Pass lava flows overlie at least part of the Sarvent lava complex in the upper part of the Ohanapecosh Formation (Fiske, 1960, p. 18), the Stevens Ridge Rhyodacite and the Huckleberry Mountain Formation (see discussions of the Mount Catherine Tuff and definition of the Keechelus Volcanic Group).

The stratigraphic relationships of these flows are much better exposed in the road cuts east of Ravens Roost lookout (EB 3), about 3 miles southeast of the southeast corner of the map area. Here a lava flow identical to the one exposed at Naches Pass overlies more than 100 feet of conglomeratic sandstone. The clasts are well rounded and range from pebbles to boulders. They consist of abundant dark-gray fine-grained andesite flow rock and light-gray hornblende andesite porphyry with coarse-grained phenocrysts of stubby prismatic plagioclase and long prismatic hornblende (Waters, 1961, p. 53-54). The conglomerate rests unconformably upon a 15-foot bed of deeply weathered well-stratified light-gray pumiceous conglomeratic sandstone, which in turn rests upon a deeply weathered dusky red saprolite zone, which had developed on lava flows of the Fifes Peak(?) Formation. Farther eastward along the road the weathered pumiceous conglomeratic sandstone is interstratified with lava flows of the Yakima Basalt.

The volcanic conglomeratic sandstone exposed between Cyclone and West Twin Creeks on the western side of the Cascade Range is similar lithologically to the sandstone immediately underlying the black porphyritic andesite flow at Ravens Roost. The sandstone is exposed in an outcrop about 30 feet long and 10 feet high. It is light gray where freshly exposed and weathers to a dark reddish brown. The clasts range in size from pebble to coarse cobble. About 5 percent of them are light-gray hornblende andesite porphyry and one percent is white pumice.

The deposit near Cyclone Creek is very similar lithologically to the continental Miocene sediments, exposed west and southwest of the map area along the Green River and South Prairie Creek and described by Mullineaux, Gard and Crandell (1959). The present writer has examined the deposits at these localities.

Gard (1960) and Waters (1961, p. 53-55) attribute the source of the hornblende andesite debris in the late Miocene sediments to the eruptive phase of the emplacement of the Snoqualmie batholith. Similar volcanic sediments along the eastern slope of the Cascade Range have been dated as late Miocene to early Pliocene, thus suggesting that the emplacement occurred during the same time. Gard believed that the source volcanoes have been removed by erosion, and subsequent erosion has deroofed the batholith. Shallow plutons structurally, texturally and mineralogically similar to the intrusions of the Snoqualmie batholith are sporadically exposed along the length of the Cascade Range. The distribution suggests that the range may be underlain by an extensive batholith (Knopf, 1955, p. 695). The presence of hornblende andesite porphyry intrusions as evidence of an underlying pluton has been sought in the map area. No intrusive rock lithologically identical to the hornblende andesite porphyry of the "Ellensburg Formation" has been found in the map area. A possible source, however, may be the altered hornblende-bearing andesite porphyry stock along the South Fork of the Cedar River.

Surficial Deposits.--Surficial deposits consist of glacial drift, landslide debris and alluvium, and are confined largely to the valleys.

Glacial deposits are extensive in the valleys of the Cedar, Green and Yakima Rivers. Mackin (1941) recognized that Chester Morse (Cedar) Lake had formed behind an embankment of debris built across the Cedar River valley by a continental glacier which had formerly occupied the Puget Sound lowland. The embankment west of Chester Morse Lake consists of detritus of northern Cascade and British Columbia provenance (Crandell, Mullineaux, and Waldron, 1958). Similar material extends southward from the Cedar River to the White River. The same material, forming till and glaciofluvium, extends along the valley of the North Fork of the Green River and along the Green River valley to near Green Canyon in the central part of the map area. Lacustrine silts and sands overlain by gravels are exposed along the Green River from Charley Creek eastward to near Maywood, indicating that the Green River valley had a history similar to the Snoqualmie River valleys (Mackin, 1941). Deeply weathered gravels of northern Cascade provenance occur at higher elevations along the Gale Creek and Sylvester Creek drainage basins, in the central part of the map area, suggesting that at least two episodes of glaciation are recorded in the map area. Scattered boulders of northern Cascade provenance also occur along the Green River valley between Champion Creek and Lester. Terraces, deltaic deposits and fanglomerates graded to the level of the terraces occur along the Green River valley west of the Howard A. Hanson dam.

Glacial deposits containing detritus of central Cascade provenance are exposed in the upper part of the Cedar River drainage basin and in the Sunday and Snow Creek drainage basins west of Stampede Pass. Both Boulder Creek and Rex River were occupied by glaciers which left deposits at the mouths of the streams south of Chester Morse Lake.

Extensive gravel deposits occur along the Yakima River valley. Weathered deposits of older glacial episodes are exposed at higher elevations along the east side of the valley. Glacial deposits occur at Lost Lake. The lake may be impounded by gravels deposited by the glaciers which occupied the Yakima River valley. Deposits, too scattered to be shown on the map, occur on the south side of Meadow Creek. They may have been derived in part from a local glacier and the Yakima valley glaciers. Glacial outwash is extensive in the Swamp Creek valley, in the east-central and along Cabin Creek in the southeastern parts of the map area.

Deposits of the Osceola Mudflow (Crandell and Waldron, 1956) occur along the White River valley.

Several landslides occur in the alunit alteration zone along the White River (Huntting, 1949). They are in part due to solution and subsidence of the leached rock, sapping of the unaltered rocks within the landslides, and undercutting the foot of the slopes by the White River.

Among the many landslides occurring in the area, the following may be mentioned. A landslide occurs in the volcanic sediments of the Cougar Mountain in the area between Gale Creek and the North Fork of the Green River. Another lies along the north side of the Howard A. Hanson dam. A third landslide occurs along the north side of the Green River at the western edge of the map area.

Intrusive rocks

General discussion.--The intrusive rocks have been separated into major and minor intrusions. The major intrusion is the Snoqualmie batholith, consisting principally of rocks ranging in composition from quartz diorite to quartz monzonite. The minor intrusions are hypabyssal rocks which consist of altered rhyolite, hornblende lamprophyre, altered pyroxene and hornblende andesite porphyry, quartz-pyroxene diorite, hornblende dacite porphyry, fresh pyroxene andesite porphyry, and fine-grained andesite. They occur as stocks, dikes and dike complexes.

Minor intrusions.--The minor intrusions have been distinguished primarily by petrography and contact relationships. They predate and postdate the emplacement of the Snoqualmie batholith.

Altered rhyolite.--Many scattered pink-weathering felsites and felsite porphyries, which occur mainly in the upper Yakima River area, have been mapped as altered rhyolite. The rhyolites occur as discontinuous dikes with irregular and commonly brecciated contacts. Many are well flow-layered. Most are too small to be shown on the map (pl. 1). They are well exposed along Cabin Creek (N 11) and along the Chicago, Milwaukee, Saint Paul and Pacific Railroad (N 9). The exposure along the same railroad west of Easton and just east of the map (I 1), may be the location at which Smith and Calkins obtained their sample of Kachess Rhyolite for analysis and petrographic study. The roche moutonnée in the middle of the Yakima River valley (I 2) is a thick dike of rhyolite about 2,500 feet long and 500 feet wide.

The dikes are possibly the feeders to the many scattered rhyolite flows in the "Naches Formation" and lower part of the Huckleberry Mountain Formation. Because these dikes do not intrude rocks younger than the Huckleberry Mountain Formation, they are dated as probable late Eocene.

Hornblende lamprophyre.--A few scattered dikes of hornblende lamprophyre are exposed in the drainage basins of Snow and Meadow Creeks. They are exposed along the U.S. Forest Service road east of Lester, along the Dandy Pass fault zone (I 3), and southwest of Meadow Mountain (I 4). A dike is fairly well exposed south of the West Fork of Snow Creek where the Scott Paper Company is quarrying the rock for road ballast. The dike is about 200 feet wide and is traceable for 3,500 feet. It trends N 40° E and dips 50° SE. The dike pinches and swells and has irregular contacts. It has a poorly developed blocky to columnar jointing. It has contact metamorphosed the wall rock up to a distance of 20 feet on either side of the contact. The rock is greenish gray and consists of about 10 percent phenocrysts in a very fine-grained intergranular groundmass of feldspar microlites, granular magnetite, and hornblende and/or pyroxene (spec. 29). About 8 percent of the rock is phenocrysts of brownish-green euhedral hornblende which occurs as prisms as long as 2 cm. The average length is one mm. About 2 percent of the rock is phenocrysts of fine-grained stubby prismatic plagioclase with a composition of about An_{55}.

The areal relationships at Meadow Mountain suggest that the hornblende lamprophyre dike had been engulfed by a cortege of altered pyroxene andesite porphyry dikes and is, therefore, older, probably middle Miocene (see discussion of altered pyroxene and hornblende andesite porphyry which follows).

Altered pyroxene and hornblende andesite porphyry.--These intrusive rocks are characterized by uralitizationof the pyroxenes, chloritization of the hornblende, and some replacement of the plagioclase by calcite and epidote. These rocks are distinguished from the much fresher and darker colored pyroxene andesite porphyry which occurs at the Rooster Comb and Kelly Butte and will be described later.

The altered pyroxene-hornblende andesite porphyry is the most common intrusive rock in the map area. They form stocks, dikes and dike complexes. Most are considered to have been emplaced prior to intrusion of the Snoqualmie batholith. The largest stock is exposed in the drainage basin of the South Fork of the Cedar River. Dikes are exposed between Rex River and Cedar River, along the fault zone at the junction of Sunday and Snow Creeks (I 5), along the Green River valley and lower Sunday Creek near Lester, along the south slope of Roaring Ridge north of Cottonwood Lake and along the southwest slope of Little Mountain. They are widely scattered in the drainage basin of Snow Creek. Many dikes occur along the Green River valley between Eagle Gorge and the Howard A. Hanson dam and to the south in the headwaters of Charley Creek northwest of Grass Mountain. The dikes in the Green River valley are believed to have been emplaced along zones of weakness adjacent to the Lemolo and Piling Creek fault zones. They may have caused much of the alteration in the breccia flows of the Eagle Gorge Andesite at the dam and west to Bear Creek. Many dikes cross-cut the Bear Creek Mudflow (HM 18). Dikes or small stocks are exposed in the upper Yakima River valley and along the divide between Friday Creek and the South Fork of the Cedar River.

The dike complexes occur at the divide between Twin Camp and Sawmill Creeks, at Pyramid and Colquhoun Peaks, in the Green Canyon area east of Rooster Comb, at Meadow Mountain and at Stampede Pass. The complexes are a mass of "dike-upon-dike" intrusions. The dikes are cross-cut or intruded along their contacts and both dike and wall rock are intensely brecciated and altered by the younger dikes.

The porphyry is commonly grayish green to dark grayish green. The rock which occurs at Colquhoun and Pyramid Peaks, at Stampede Pass, and at the south side of Meadow Mountain is olive black. This rock is probably the porphyry which Smith and Calkins (1906, p. 9) considered to be forming the periphery at Meadow Mountain (spec. 30). It is slightly fresher and contains fewer mafic phenocrysts than the lighter colored variety with the exception of the hornblende-rich stock along the South Fork of the Cedar River.

The rocks contain 20-30 percent phenocrysts of which 15-25 percent is plagioclase and the rest is ferromagnesian minerals. Augite exceeds hypersthene in amount. If hornblende is present, as in the stock, it exceeds the amount of augite. Plagioclase is generally the coarsest phenocryst, up to 3 mm but averages 1 mm. A few prisms of hornblende are as long as 1 cm. The plagioclase phenocrysts form stubby prisms and commonly show oscillatory and patchy zoning. Their composition is An_{27-58} and they are altered in part to calcite, sericite, and epidote. Epidote is especially abundant in the stock. Hypersthene is largely altered to uralite and magnetite, augite to chlorite, magnetite and calcite, and hornblende to chlorite and calcite. The groundmass has a very fine-grained allotriomorphic granular texture. The Stampede Pass intrusion has a pilotaxitic groundmass. Much quartz is disseminated in the groundmass of some porphyries and indicates a transition to dacite in composition. Zeolites and unidentified olive-green to brown micaceous mineraloids are commonly present.

The contacts of the dikes are not well exposed. Wide massive vertical dikes are well exposed on the north side of Meadow Mountain. They have a columnar-like horizontal jointing. The dike complex north of Twin Camp Creek consists of a network of sills and dikes. The brecciation of the Stampede Pass complex is well exposed along the Bonneville Power Administration right-of-ways east of Sunday Creek. Sizeable blocks of stratified volcanic rocks occur between parts of the complexes.

Most of the dikes and dike complexes have been emplaced along or adjacent to faults, suggesting that the dikes postdate the major structural deformation of the area. The pyroxene andesite porphyry is believed to intrude the hornblende lamprophyre dike at Meadow Mountain, although the contacts are not exposed. The stock in the South Fork of the Cedar River is intruded by quartz diorite of the Snoqualmie batholith. The contact is exposed along the road south of Bear Creek (I 6). These rocks are not younger than middle Miocene.

The writer reconnoitered the area northeast of Blowout Mountain for the pyroxene diorite intrusion of Smith and Calkins (1906, p. 9) and the basalt porphyry and quartz gabbro intrusion of Stout (1959, p. 143-146). He could find no evidence of an intrusion in the area. The rock is primarily pyroxene andesite porphyry lava flow which overlies the Blowout Mountain Flow Member of the "Naches Formation." These rocks are exposed along the crest of the Snowshoe Butte anticline and are well fractured, which has in a large part obscured their generic features. The writer does not know the location from where Stout (1959, fig. 59) obtained his specimen for study.

The writer did not visit the Tacoma Pass area where Smith and Calkins located another pyroxene diorite and Stout (1959, fig. 51 and 52) mapped an olivine diabase.

Quartz-pyroxene diorite.--Several dikes and small stocks of quartz-pyroxene diorite have been mapped. The dikes are located along the Bonneville Power Administration right-of-way west of Lake Keechelus (I 7), along the road between Seattle Creek and the South Fork of the Cedar River, along the ridge of Findley Lake, and in the dike complex at Meadow Mountain. The stocks are located at Grass Mountain, on the floor of the upper Yakima River valley near the Chicago, Milwaukee, Saint Paul and Pacific Railroad. On the southwest slope of Mount Kent, which lies off the edge of the map, at Silver Peak along the Cascade crest, east of Goat Mountain south of the South Fork of the Cedar River, and along Roaring Ridge north of Los Lake west of Lake Keechelus. The rock also occurs as lenticular bodies along the contact between the altered hornblende-rich andesite porphyry stock and the Snoqualmie batholith and is probably a border phase of the larger pluton.

The rock is medium to dark greenish gray, fine- to medium-grained, and has a holocrystalline allotriomorphic granular texture (spec. 31). It consists of about 60-75 percent prismatic plagioclase, as much as 15 percent augite and 5-15 percent interstitial quartz. Uralite, magnetite, calcite, sericite, and epidote are accessory and secondary minerals. The plagioclase has patchy and oscillatory zoning and a composition of An_{41-62}. It is partially altered to calcite, sericite and a very little epidote. Augite is almost entirely replaced by uralite, calcite and magnetite.

The contacts are generally poorly exposed except along the road south of Bear Creek (I 6). Here the diorite has a sharp irregular contact with contact metamorphosed hornblende andesite porphyry. Metamorphosed xenoliths, 1 inch-3 feet in size, of the porphyry and fragmental volcanic rock is exposed along the intrusive contact. The xenoliths have probably not been transported very far from their original position within the melt because the areal distribution of the andesite porphyry, which here intrudes stratified volcanic rock of the Snow Creek Formation, indicates that this area is near the northern border of the porphyry pluton.

The border relationship and its position within the Meadow Mountain dike complex indicate that the quartz-pyroxene diorite is younger than the pyroxene-hornblende andesite porphyry and is slightly older or the same age as the Snoqualmie granodiorite. It is no younger than middle Miocene.

Hornblende dacite porphyry.--Small stocks, bosses, and irregular dikes and dike complexes of hornblende dacite porphyry are exposed in the eastern half of the map area. These rocks are recognized by the presence of quartz and hornblende phenocrysts. They may in part be transitional with the altered pyroxene and hornblende andesite porphyry dikes and, therefore, some of these rocks may be older than the Snoqualmie batholith. Bosses are exposed at Mount Gardner in the north-central part of the map area where the porphyry intrudes the Snoqualmie batholith and north of Kelly Butte. An intensely argillized intrusion is exposed north of Lake Albert along the South Fork of the Cedar River. Dikes are exposed between the West and Middle Forks of Snow Creek, along the abandoned logging railroad grade south of the Cedar River (I 8), where the dacite porphyry intrudes the Snoqualmie batholith. East of Rex River the porphyry intrudes the Cougar Mountain Formation. The porphyry also occurs along the east side of Champion Creek. The hornblende dacite porphyry forms a dike complex in the area between McCain Creek and Green Canyon in the central part of the map area.

The rock is dark greenish gray and weathers to a greenish gray (spec. 32). It is distinctly porphyritic and contains up to 35 percent phenocrysts which lie in a cryptofelsite groundmass. The phenocrysts range up to 8 mm in length and include about 25 percent prismatic plagioclase, 5 percent quartz and 5 percent hornblende. The plagioclase is zoned and has a composition of An_{36-57}. The crystals are embayed and the mineral is partly replaced by epidote. The quartz is also embayed. The hornblende is almost entirely replaced by chlorite, calcite, and magnetite. A few pseudomorphs have squarish outlines, suggesting the former presence of pyroxene.

The contacts of the hornblende dacite porphyry intrusions are very poorly exposed except in the dike complex along McCain Creek. Contacts with the Snoqualmie batholith were not observed. Generally the rock has a very narrow contact zone, less than about 3 feet, except at McCain Creek. At McCain Creek the wall rocks are contact metamorphosed and highly fractured, suggesting the presence of a subjacent satellite of the Snoqualmie batholith. Intense fracturing of the wall rock proceeded emplacement of the satellite making avenues for the cortege of dacite porphyry dikes which followed. The relationship of the dacite porphyry dikes to the altered pyroxene porphyry dike complex is not known. The contact between the two rock types was not located in the field but is determined by the positions of a few scattered outcrops of the rocks and interpretation of the general outcrop features shown on aerial photographs. Because the rock intrudes the

Snoqualmie batholith at Cedar River and Mount Gardner, the hornblende dacite porphyry is considered to be post-Snoqualmie batholith in age and about middle Miocene.

Pyroxene andesite porphyry.--This pyroxene andesite porphyry is distinguishable from the altered pyroxene andesite porphyry by its darker color and freshness. It has been found at only two locations--Rooster Comb and Kelly Butte--in the central part of the map area. Rooster Comb is a small stock. It has a well-developed exfoliation jointing. Weathering has peeled slabs from the mountain and has formed a cone-shaped landmark, hence the name. Kelly Butte is a well-exposed dike complex. Large blocks of horizontally stratified lapilli-tuff and coarse volcanic sediment of the Huckleberry Mountain Formation are exposed between the dikes atop the butte (see pl. 1). The dikes are vertical, have a well-developed horizontal columnar jointing, and are up to 400 feet thick.

The rock is olive gray to dark greenish gray (spec. 33). The phenocrysts range from ½-2 mm in size and make up about 40 percent of the rock. They include 25-35 percent plagioclase and 5-15 percent pyroxene, most of which is augite. The texture of the groundmass is variable. It is cryptocrystalline at Rooster Comb and is coarse grained and subophitic at Kelly Butte. The phenocrysts are finer grained at Rooster Comb. The plagioclase phenocrysts occur as stubby prisms, have oscillatory zones and contain abundant pyroxene inclusions. The plagioclase composition is An_{48-75}. The average An-content of the plagioclases at Kelly Butte tends to be higher. The pyroxenes are finer grained than the plagioclase phenocrysts and are altered slightly to chlorite. The groundmass consists mostly of plagioclase laths and granular pyroxene and magnetite.

The intrusions have a very narrow contact metamorphic aureole. Along Smay Creek the Rooster Comb intrusion has not indurated the wall rock beyond 15 feet from the contact. The stratified volcanic rocks of the Huckleberry Mountain Formation are locally disrupted. Contact metamorphism at Kelly Butte had the same effect. There is little evidence of disruption of the strata even in the blocks exposed at the butte.

The Rooster Comb and Kelly Butte intrusions are tentatively considered to be post-Snoqualmie granodiorite in age. This consideration is based on the relatively fresh appearance of the rock in comparison with the other hypabyssal intrusions. The fresh pyroxene andesite porphyry was not found in contact with other intrusive rock.

Andesite.--Andesite dikes are scattered throughout the map area. They are generally narrow and are irregular. Most of andesite intrusions are not shown on the map. They are most abundant in the highly fractured contact metamorphic aureole of the Snoqualmie batholith along the slopes above Chester Morse

Lake and Little Mountain, along Roaring Ridge north of Cottonwood Lake where they form a small complex, and at Tinkham Peak. Several dikes intrude the Huckleberry Mountain Formation north of the Howard A. Hanson dam site.

The andesite is dusky blue green to greenish gray, averages about ¼ mm in grain size, and contains less than 5 percent plagioclase phenocrysts (spec. 34). They appear to be a fine-grained equivalent to the quartz-pyroxene diorite intrusions. They are holocrystalline and have a hypidiomorphic granular texture. Some have a weakly developed pilotaxitic texture. They contain about 85 percent zoned plagioclase of An_{55-62}, 10 percent anhedral augite which is altered in part to uralite and chlorite, and about 5 percent interstitial quartz. They contain minor amounts of magnetite and calcite. The contacts are irregular although sharp. Little to no thermal effects are present. Along the east side of Rex River an andesite dike has intruded along the contact between altered pyroxene andesite porphyry and metamorphosed Cougar Mountain Formation. Along the north side of Chester Morse Lake the dikes have weathered leaving wide fissures in the contact metamorphosed country rock. One dike cuts the small stock of quartz-pyroxene diorite near Mount Kent (I 9). These relationships suggest that the andesite dikes were intruded after emplacement of the Snoqualmie batholith.

Snoqualmie granodiorite.

Distribution.--A large pluton of predominantly granodiorite, quartz diorite, and a minor amount of quartz monzonite occurs in the north-central part of the map area (pl. 1). The rocks were originally described by Smith and Mendenhall (1900) and later mapped by Smith and Calkins (1906) who named it the Snoqualmie granodiorite. Subsequently, Fuller (1925) showed that the pluton extends westward from the Snoqualmie Pass area and consists of at least four phases. He designated the pluton as the Snoqualmie batholith. Now the name Snoqualmie batholith is used indiscriminantly (Knopf, 1955, p. 695; Waters, 1955, p. 711) without regard for the original designation as Snoqualmie granodiorite. The present writer retains the name Snoqualmie granodiorite for the plutonic rock in the map area because (1) the pluton is continuous with that mapped by Smith and Calkins, and (2) the name designates a lithologic unit which occupies a position in the geologic column.

Only parts of the pluton in the map area have been examined in the course of this study. It is generally poorly exposed. The interpretation of the rock types and their distribution is based primarily on the exposures along the Cedar River, Bear Creek, the ridge between the Snoqualmie and Cedar Rivers, Hansen Creek and the Chicago, Milwaukee, Saint Paul and Pacific Railroad north of the map area.

Most of the pluton appears to consist of granodiorite. It has a border zone of quartz diorite. The zone is very irregular and much of the pluton in the area may consist entirely of quartz diorite. Quartz monzonite is exposed for about 1,000 feet along the road along the Cedar River (I 10). Transitions between the rocks cannot be followed in the field because of poor exposure. The small pluton along the South Fork of the Cedar River and the many dikes at Findley Lake, along the Cedar River to the west of the main body, and north of the Rex River consist of quartz diorite. The pyroxene diorite which Fuller (1925, p. 72-76) recognized along the south side of the Cedar River may be one of these isolated quartz diorite intrusions.

Petrography.--The rock consists almost entirely of plagioclase, quartz, orthoclase, biotite and hornblende. It is massive; the biotite and hornblende are uniformly scattered through the rock. It has an allotriomorphic granular texture in which the grains average 1 mm in size. Change in the proportion of plagioclase, quartz and orthoclase accounts for the variation in the composition of the pluton. Quartz and orthoclase increase at the expense of plagioclase in the transition of quartz diorite to quartz monzonite. The variations can be distinguished in the field by their color. Quartz diorite (spec. 35) is a very light greenish gray, granodiorite (spec. 36) a light pink greenish-gray, and quartz monzonite (spec. 37) is a very pale brownish gray.

The rock contains 45-55 percent plagioclase, 18-35 percent quartz, 12-18 percent orthoclase, 4-7 percent biotite and 2-6 percent hornblende. Magnetite, apatite, rutile, and zircon are accessory minerals. The plagioclase is prismatic, has patchy and oscillatory zoning, and generally ranges in composition from An_{23-48}. Greenish-brown biotite and green hornblende are anhedral and rarely poikilitic. Quartz and orthoclase are interstitial. The orthoclase is a product of late magmatic crystallization, for no evidence of replacement of plagioclase could be found in the thin sections.

Along the north side of the Cedar River and Bear Creek the pluton is intensely fractured, altered and locally contains disseminated sulphide minerals. Alteration is intense along the fracture zones. Chlorite has replaced biotite. Chlorite and sphene have replaced hornblende. Sericite and minor amounts of epidote have partly replaced plagioclase. In the most intense alteration zones the rock is largely replaced by quartz, sericite, and small amounts of tourmaline. Some fractures are lined with quartz, chlorite and tourmaline. Sulphide minerals, consisting mostly of pyrite, a little chalcophyrite, and very minor amounts of molybdenite occur along the fractures or disseminated in chlorite patches. The alteration is probably hydrothermal, because it equally affects quartz diorite, granodiorite and quartz monzonite and occurs adjacent to the fracture zones.

Contact relations.--The contacts of the pluton are not well exposed and have not been traced in the field. They have been approximately located at various points and traced between these points on the aerial photographs. The contacts, where exposed, are both gradational in one area and sharp in others. The contact exposed along the Cedar River road (I 11) is gradational. Here along a zone about 200 feet tuff-breccia is gradational into biotite-diopside hornfels, in which none of the fragmental texture is preserved, and the hornfels is gradational into chloritized hornblende-quartz diorite. No clean separation occurs between the rocks. The zone is intricately intruded by diorite dikes 1-2 feet thick. A few quartz-tourmaline veinlets and clusters of epidote and tourmaline occur in the hornfels. About one mile east the hornblende-quartz diorite is transitional into the quartz monzonite in the W½ sec. 32.

The contact is sharp where exposed along the road south of Bear Creek (I 6) (see discussion of minor intrusive rocks). It is very irregular. Rounded to subrounded xenoliths, 1 inch-3 feet in size, of hornfelsed hornblende andesite porphyry and tuff-breccia are randomly distributed and oriented in a zone averaging about 50 feet wide. Irregular shaped bodies of pyroxene diorite occur within the zone adjacent to the contact. Many dikes, up to 2 feet wide, of diorite extend irregularly along fractures in the adjacent hornblende andesite porphyry.

The contact is probably more irregular than is shown on the map.

The grade and extent of contact metamorphism (see discussion of metamorphism) around the pluton and the distribution of small diorite intrusions provide some information regarding the shape of the pluton. The distribution of contact metamorphism and the many dikes and small stocks of pyroxene diorite and quartz diorite to the west suggest that the pluton underlies almost all the area north of the Cedar River and that it has probably an irregular top consisting of many apophyses. In contrast, to the east there are no small diorite intrusions and the metamorphic zone is uniformly distributed along the eastern contact of the pluton. The outcrop pattern suggests that the southern end of the pluton has two prongs, an east prong extending under the South Fork of the Cedar River and a west prong extending beneath Findley Lake. The lack of contact metamorphism in the area of the South Fork suggests that the east prong terminates at the hornblende andesite porphyry stock. An apophysis with steeply dipping contacts and presumed to have risen from considerable depth, is exposed along the southern side of the porphyry stock. In contrast the extent of metamorphism and the few diorite dikes at Findley Lake indicate that the west prong extends farther to the south and probably underlies Findley Lake at a shallow depth.

The hornfels zone west of the pluton is irregularly fractured and intruded by many fine-grained andesite dikes which in part cut the small diorite intrusions. These relationships suggest that some deformation occurred after emplacement of the pluton.

Age.--The Snoqualmie granodiorite has been dated radiogenically as 17.0 million years, about middle Miocene. Specimens were collected along U.S. Highway 10 east of Olallie Creek (I 12). The dating was determined by the K-Ar method, using biotite obtained from the specimens (Curtis, Savage and Evernden, 1961, p. 347; Lipson, Folinsbee and Baadsgaard, 1961, p. 460). The rock exposed at Olallie Creek is hornblende-biotite quartz diorite identical to the rock in the border zone along the Cedar River. Larsen, Keevil and Harrison (1952, p. 1050), using the zircon method, obtained an age of 63 million years, upper Paleocene, which they considered as a poor measurement, for Snoqualmie granodiorite, but did not specify the location from which they took their sample. The youngest stratified rock intruded by the Snoqualmie granodiorite is the Cougar Mountain Formation, which is tentatively considered as early (?) Miocene.

Fuller (1925) believes that the Keechelus volcanic rocks were the effusive equivalents of the Snoqualmie granodiorite which was deroofed during the emplacement and that the pyroxene diorite plutons at Silver Peak and Meadow Mountain formed in the vents during the final phase of the emplacement. Waters (1961) likewise believes that the upper Keechelus of Smith and Calkins (which Waters redefined as Ellensburg Formation) was formed during a volcanic phase accompanying the emplacement of the Snoqualmie and Tatoosh plutons. He (p. 53-55) believes that the glassy "andesites" which constitute a large portion of the volcanic materials in the Ellensburg Formation were derived in part from the stocks exposed north of Naches Pass (see Waters, 1961, pl. 1). Fuller's and Waters' reasoning is based in part on the belief of Smith and Calkins (1906, p. 9) that these stocks represented the roofs of the volcanoes from which the Keechelus volcanic rocks were derived. At Meadow Mountain Smith and Calkins believed there is evidence showing the transition of intrusive rock into flow rock. The intrusions may be sources of a part of the volcanic detritus in the Ellensburg although this possibility cannot be clearly demonstrated by petrologic comparison of the rock types. However, it can be reasoned that these plutons, including the Snoqualmie granodiorite, are not the sources from which the Keechelus rocks were derived. All the plutons are intrusive into the Keechelus, they stand in relief almostas much as 1,000 feet above the adjacent stratified rocks, including the upper part of the Snow Creek Formation, and they were emplaced after the Keechelus rocks had been structurally deformed, zeolitized (see discussion of alteration and metamorphism) and eroded. The intrusive rock at Meadow Mountain is petrographically similar to the flow rocks of the Keechelus, as well as to Ohanapecosh, Fifes Peak and

Cougar Mountain . However, the relationships exposed at Meadow Mountain do not indicate that the rocks are transitional into flows. No intrusive rock can be traced laterally into a stratified flow rock. The probability that such a relationship should exist at Meadow Mountain is highly implausible in view of the time, since about middle Miocene, that the mountain may have been exposed to erosion. It is not improbable that some of the plutons, possibly the ones west of Meadow Mountain or at Goat Mountain, contributed material to the Cougar Mountain Formation. If the stocks are the exposed vents of volcanoes, it is more likely that their effusive products accumulated as deposits which have long since been eroded from the central Cascade Range, very likely before the outpouring of the Columbia River basalts.

Alteration and metamorphism

General discussion.--The alteration and metamorphic features of the Keechelus volcanic rocks were originally noted by Smith and Calkins (1906, p. 8-10) and summarized by Waters (1955, p. 710). A detailed summary of these features and their relationship to the structures and intrusions in the area is beyond the scope of this study. Only a brief discussion is made herein of some of the characteristics of the alteration and metamorphism, based primarily on the field study and examination of a few thin sections. The discussion concerns alunitization, zeolitization and contact metamorphism.

Alunitization.--Kirkemo (1940) and Huntting (1949, p. 46-47) described the occurrence of alunite along the Green River in Tps. 19 and 20 N., R. 8 E. Here lava flow and tuff-breccia of the Enumclaw Formation are locally brecciated and replaced by quartz, alunite, jarosite, pyrite and minor amounts of clay minerals. An intensely silicified area, consisting of gray jasperoid quartz with a vuggy texture, occurs at "Quartz Mountain" between the White River and U.S. Highway 410 (A 1). The silicified area is surrounded by a zone of alunitization. The alunite and jarosite have locally replaced the pyroxene andesite porphyry, converting it to a soft clayey, very light-gray to grayish-yellow mass in which the plagioclase phenocrysts outlines and some flow lines are preserved. Disseminated fine-grained euhedral pyrite is abundant. In contrast, intense brecciation and silification has obliterated the original textures of the rock. Additional alteration was noted by the present writer between Clay and Cyclone Creeks (A 2).

The alunitization is irregular in its distribution although it is common along the White River valley near the mouth of the Clearwater River. The alteration is of fumarolic or epithermal origin. The solutions may have migrated in part along the Twin Creeks fault, located north of the White River. The silicified zone may lie along an undetected northeast-trending fault, paralleling the course of the White River in that area.

Zeolitization.--Zeolitization of the early Tertiary volcanic rocks in the Cascade Range has been noted by Waters (1955, p. 704-710). It consists of partial replacement of the rock by prehnite, zeolites (heulandite, laumontite, stilbite, and natrolite) and iron-bearing clays (celadonite and nontronite). Fiske (1960, p. 92-100) described zeolitization of the Ohanapecosh Formation and considered the alteration equivalent to the zeolitic facies of regional metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 215-217). A zeolite in the Ohanapecosh Formation has been recognized as wairalite by Wise (1959).

The writer suspects that the zeolitization is partly a result of diagenesis and very low-grade regional metamorphism. The alteration, regardless of its cause, is characteristic of the fragmental basic andesite rocks in the lower Tertiary of central Washington, including the Tukwila and Ohanapecosh Formations, the Keechelus Volcanic Group, the Silver Pass volcanics (Foster, 1960, p. 105-107), and probably the Fifes Peak Andesite. It is a feature characteristic of most of the volcanic rocks deposited prior to the middle Miocene orogeny which culminated with the emplacement of the Snoqualmie granodiorite and related plutons. The zeolitization has indurated the rocks, making them massive and dull colored. These features aid in distinguishing these rocks from the younger volcanic formations, the Cougar Mountain and Ellensburg Formations.

In the west-central Cascade Range, zeolite, calcite and a minor amount of chalcedony occur as amygdaloidal fillings, as fracture fillings, as fillings along the boundaries of lithic and pumice fragments, especially in breccia flow and coarse tuff-breccia, and as replacement of feldspars. The zeolites are recognized by their crystal habit (prismatic to sheaflike aggregates), hardness, and lack of reaction with dilute HCl. They occur in rocks in which the vitric constituents have been altered to clay, producing a dull-colored rock, in various shades of gray, green, and blue. Weathering and oxidation of the altered rock changes the color to brown. The alteration affects the entire rock, except large dense lithic fragments. It is most common, decreasing in the order given, in breccia flow, tuff-breccia, volcanic sediment, tuff, and lava flow. The alteration is not restricted to a particular rock type, formation or structural horizon. It is erratically distributed in all the formations of the Keechelus Volcanic Group and is rarely present in the Cougar Mountain Formation. Unaltered volcanic rock occurs in the Enumclaw as well as the Cougar Mountain Formation. Some argillic, hematitic and possibly zeolitic alteration occurs in the Cougar Mountain Formation along Boulder Creek and in the Goat Creek amphitheater. At Boulder Creek the alteration is probably deuteric, and at Goat Creek, it has probably been caused by deuteric solutions arising from the adjacent andesite porphyry stock.

The zeolitic alteration is spatially related to the geologic structure. It is most intense along the Snowshoe Butte anticline, from Snowshoe Butte westward to Piling Creek. Zeolites are especially abundant as fracture fillings within the rock in the axial part of the fold. The alteration is structurally controlled and related to the isogeotherms which rose to a higher level along the zones of maximum compression in anticlines. In addition, the isogeotherms were probably locally elevated over subjacent plutonic bodies. The extent of zeolitization possibly fluctuated during the early Tertiary in relation to the time and location of volcanic activity, occurring in different areas at various times and advancing at the culmination of the middle Miocene orogeny. In middle Miocene the distribution of zeolitization was transected by the zones of contact metamorphism adjacent to the plutons (see fig. 1).

Contact metamorphism.--The small plutons have narrow contact metamorphic aureoles less than 25 feet wide, except at the quartz-pyroxene diorite stock at Grass Mountain. The most extensive and varied contact metamorphism is associated with the Snoqualmie granodiorite. At least four grades of hornfels are recognizable in hand specimen and thin section: actinolite, biotite, biotite-diopside and biotite-hypersthene hornfels. The distribution and grade of hornfels is related primarily to the composition of the country rock and the spatial distribution of the adjacent

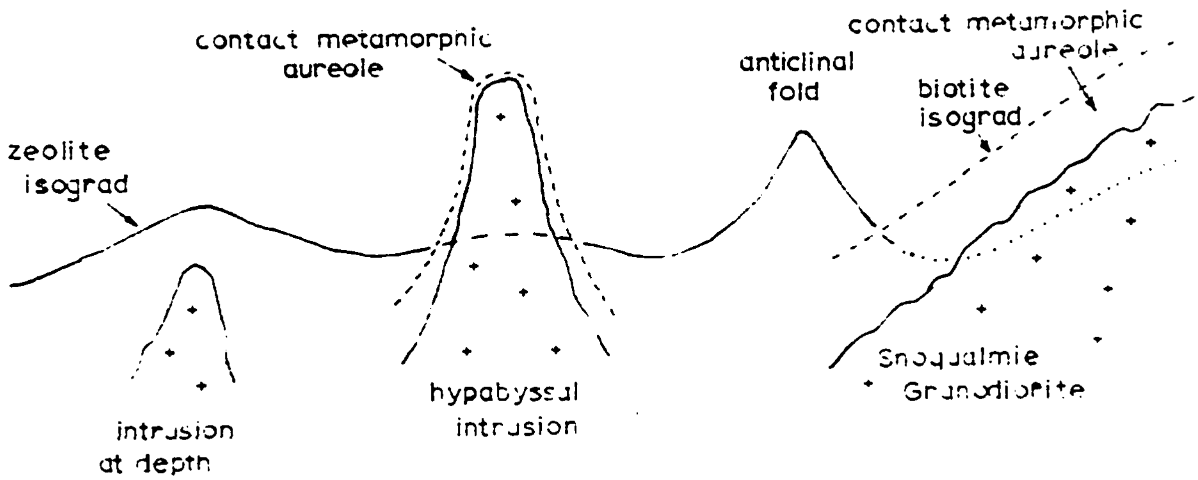


Figure 1. Cross-section showing hypothetical relationship between zeolitization and contact metamorphism, based on field observations in the west-central Cascade Range.

Zeolite isograd is generally shallow but rises over subjacent plutons. It rises steeply into the core of an anticlinal fold (Snowshoe Butte anticline). The zeolite isograd is transected sharply by a narrow contact metamorphic zone about a hypabyssal intrusion. The isograd about the hypabyssal intrusion and the zeolite isograd are transected by a moderately inclined biotite isograd, marking the outer limit of contact metamorphism of the Snoqualmie batholith. It is assumed that the shallow plutons moved upward faster than the isotherm and overtook the zeolite isograd.

Snoqualmie granodiorite. The grade of hornfels is further affected by hydrothermal alteration.

The original textures of the contact metamorphosed volcanic rocks are best preserved on a weathered surface. However, the fragments are not easily discernible in a fresh hand specimen or thin section. The fragments can be identified microscopically by clusters of minerals. A tuff or pumice fragment has been commonly converted to a cryptofelsite aggregate containing abundant fine-grained brown biotite. Biotite also occurs in stringers or trains outlining the former vitroclastic texture of a vitric tuff. A probable flow rock fragment has been metamorphosed to either a mosaic of biotite, feldspar and a few diopside crystals or much diopside and blastoporphyritic crystals of plagioclase. Disseminated fine-grained granular magnetite is ubiquitous. Hypersthene occurs as disseminated very fine-grained crystals. Hypersthene is most common in the contact zone along the south side of the Grass Mountain pluton. Epidote is commonly a minor constituent in all the contact metamorphic rocks in the map area. Hornblende is common in the western contact zone gradational with the Snoqualmie granodiorite along the Cedar River. Actinolite is possibly indicative of low grade contact metamorphism and hydrothermal alteration. The hydrothermal alteration is characterized by the formation of chlorite (penninite is common in veinlets), quartz, tourmaline and pyrite. Epidote is more abundant in the altered zones than in hornfels. Plagioclase is partly replaced by aggregates of calcite and sericite. Locally intense zones of pyritization, which weather to form a brownish-red gossan, are discernible in the field from a distance.

Biotite hornfels is extensive along the eastern side of the Snoqualmie granodiorite pluton. Diopside hornfels is common at the western side and along the Cedar River valley to Little Mountain. The Cougar Mountain Formation has been converted to diopside hornfels southeast of Little Mountain (A 3). Epidote and tourmaline are abundant along Seattle Creek (A 4). Along Tinkham Creek (A 5) tuff-breccia has been replaced almost entirely by coarse-grained aggregates of epidote and chlorite. Hydrothermal alteration occurs along the northern side of Grass Mountain (A 6), and within the Annette Lake cirque at the head of Humpback Creek. Pyritization is sporadically located in the saddle between Silver Peak and Abiel Mountain and along the lower north slope of Abiel Mountain.

STRUCTURE

Regional structure

The map area (pl. 1) includes the structural downwarp of probable middle Miocene age between the Tatoosh pluton, in Mount Rainier National Park (Waters, 1961), to the south, and the Snoqualmie batholith, centered approximately in the northeastern part of King County, to the north (see pl. 4). The southeastern extension of the Newcastle Hills-Tiger Mountain anticlinal high (Weaver, 1916, pls. IVB and XXX) lies along the western border of the area. The Thorp Mountain-Cle Elum Ridge anticlinal high, a major structure which extends from the Cascade crest to Lake Kachess and the southern side of the Yakima River valley to the Columbia Plateau, trends southeastward east of the area. The eastern part of the area lies athwart the north-south axis of the late Pliocene arching of the Cascade Range.

The structures are shown simplified in plate 21.

Folds

General features.--The stratified units have been warped to form an intricate system of open, upright, en échelon folds. The Lindsay syncline has a maximum width of 6 miles. The tight folds

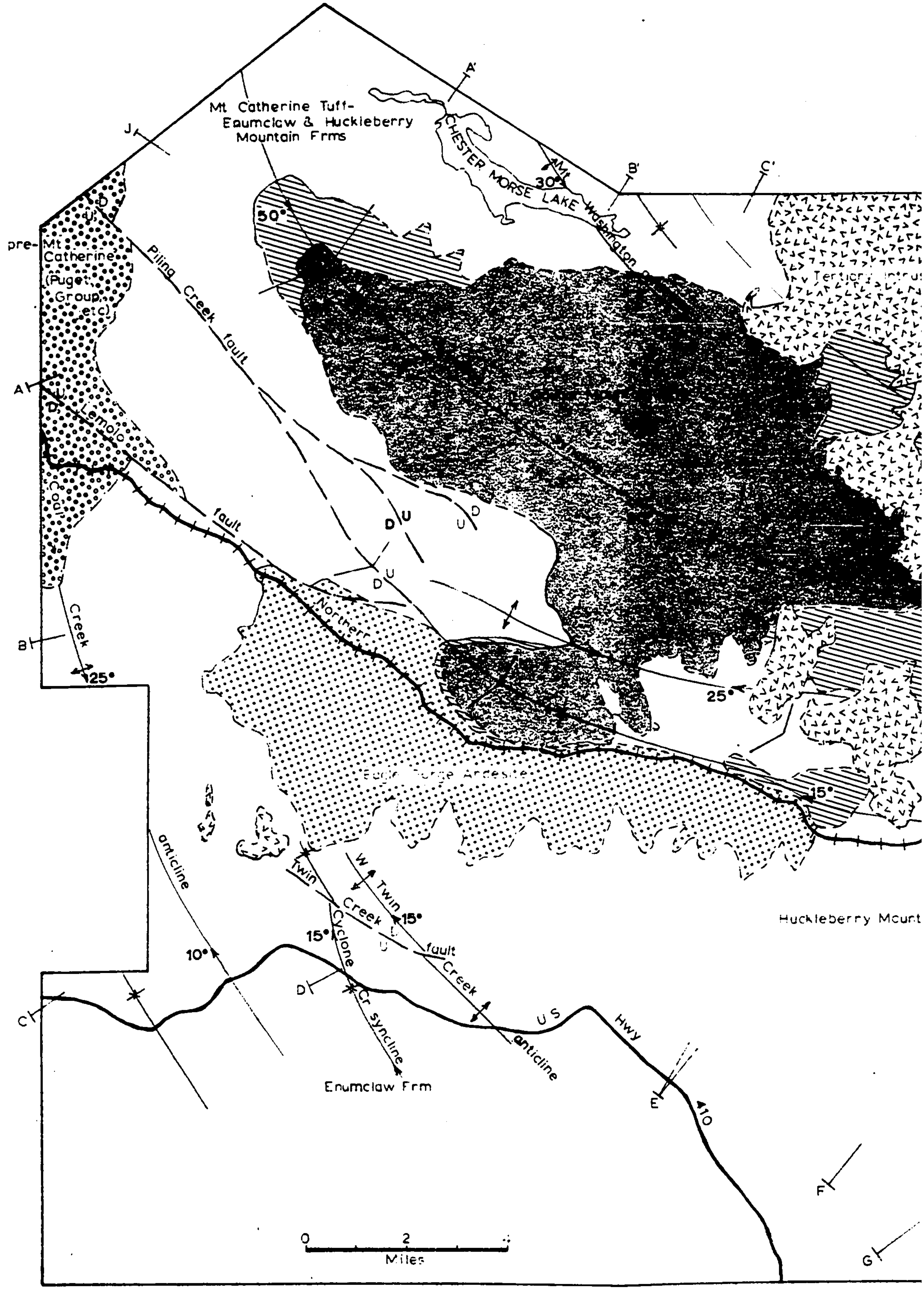
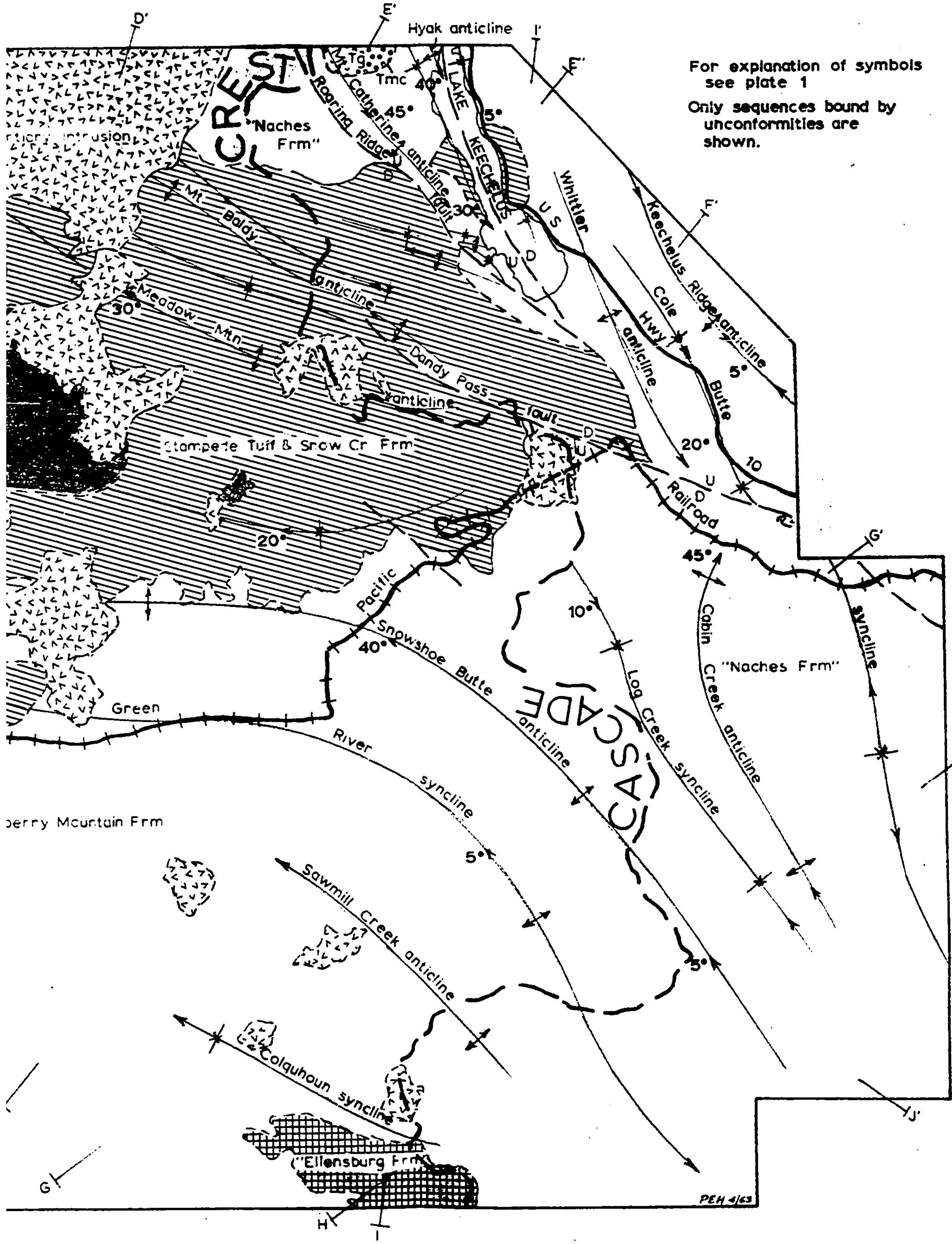


Plate 21. Structure Map of Wes



of West-central Cascade Range, Washington within the strata of the "Naches Formation" southwest of Lake Keechelus have a minimum width of one-quarter of a mile. Extremely tight disharmonic folds occur in the carbonaceous sedimentary strata of the "Naches Formation" exposed north of Cole Butte in the southeastern corner of the area. The folds trend generally northwestward except north-northwestward along the Cascade foothills between the White and the Cedar Rivers and between the Naches River and Cle Elum Ridge in the southeastern part of the map area. The folds are doubly plunging. Those located south of the Green River plunge very gently northwestward. The Lindsay syncline, along the north side of the Green River, plunges about 20° toward the center of its trough, located in the headwaters of Rex River. The Mount Catherine and Cabin Creek anticlines plunge as steeply as 45° along short distances of their lengths.

Locally the crestal parts of the folds are disrupted by minor folding and faulting. The Snowshoe Butte anticline, in the central part of the map, is disrupted in the area between Gale and Boundary Creeks and along the west slope of Snowshoe Butte. The Cabin Creek anticline, in the southeastern corner of the area, is disrupted between Cabin Creek and the upper Yakima valley.

In the Cyclone Creek area along the north side of the White River, in the North Fork of the Green River area, and in the Lake Keechelus area the axial planes of the folds are either terminated by faults or coincide with the strike of the fault planes.

The irregularity of the folding is probably due to: (1) the wide variation in competence of the rocks, which range from massive lava flow and tuff-breccia to thin-bedded carbonaceous sedimentary rock, (2) the variable thickness and lenticularity of the stratigraphic units, and (3) the variable depth to crystalline bedrock.

Lindsay syncline.--The Lindsay syncline is the major structural feature within the map area. It is the axis of the structural downwarp between the Tatoosh pluton and the Snoqualmie batholith. It trends westward and northwestward through the center of the area between the Green River and Cedar River valleys from Stampede Pass beyond the map area to Rattlesnake Mountain in the North Bend quadrangle for a distance of at least 35 miles. The Cougar Mountain Formation is preserved largely in its trough. The fold is most tightly compressed in the northwestern part of the area. At its eastern end the fold is mildly disrupted by faulting along Snow and Sunday Creeks, by the emplacement of the dike complex at Stampede Pass, and it is terminated by the Dandy Pass fault. In the northwestern part the fold plunges 50° SE and in the eastern part 20° W.

Green River syncline.--The Green River syncline lies south of the Lindsay syncline, trending along the Green River valley. It extends from Boundary Creek, where it aligns northwestward with the Piling Creek fault zone, southeastward into the drainage of the Naches River, a distance of 24 miles in the map area. The fold has been traced for an additional 15 miles along the Naches River southeast of the map area. The fold is sinuous along its length and plunges irregularly. It plunges southeastward from Boundary Creek to the area just north of Humphrey; from the Cascade crest it plunges northwestward and southeastward. The plunge is 15° NW in the area between Nagrom and Hot Springs; elsewhere the plunge is 5° to 10°. The abrupt increase in degree of plunge and minor faulting along the fold in the Green Canyon-McCain Creek area is probably caused by the emplacement of the dike complexes there.

Snowshoe Butte anticline.--The Snowshoe Butte anticline separates the Lindsay and Green River synclines. The fold parallels and has about the same length as the Green River syncline. It is disrupted where it coincides with the Piling Creek fault zone, in the area of the East Fork of Smay Creek and on the west slope of Snowshoe Butte. The fold is well exposed along Gale Creek and in the ridge northeast of Blowout Mountain. It plunges 5-25° NW from Blowout Mountain to the area between Cougar and Sylvester Creek where it flattens. Along the west slope of Snowshoe Butte it plunges as steeply as 40° W.

Keechelus Ridge anticline.--The Keechelus Ridge anticline is the major fold along the eastern border of the map area. It trends southeastward from the west slope of Kendall Peak north of the map area through Keechelus and Ambalis Ridges. The fold plunges about 5° SE toward Swamp Creek. The position and attitude of the sandstone beds exposed along the road north of Swamp Creek suggest that the axial plane of the fold dips eastward.

Cole Butte syncline.--The Cole Butte syncline lies in the southeastern part of the map area, extending northward from Cole Butte along Cole Creek to the upper Yakima River valley. Here the fold is truncated by the northwestward-trending Dandy Pass fault, which has displaced the syncline to a position where it lies along the west slope of Keechelus Ridge. The fold plunges beneath the upper Yakima River valley.

Minor folds.--The Coal Creek anticline, Cyclone Creek syncline, West Twin Creek anticline, Colquhoun Creek syncline and Sawmill Creek anticline lie south of the Green River and are open gentle folds trending northwestward to north-northwestward diagonally across the broad gently northward-dipping homocline which extends from the Tatoosh pluton to the Green River. The Coal Creek anticline extends along the western border of the map area from south of the White River to west of Palmer Junction, a small community located on the Green River west of the map area. The fold is probably the northwestward continuation of the Huckleberry Park anticline mapped by Fiske (1960, pl. 1). The fold had been previously delineated by Warren and others (1945). North of Palmer Junction the fold is probably truncated by the Lemolo fault which trends northwestward along the north side of the

Green River. The fold plunges about 25° SSE into the area near Grass Mountain. South of the White River it plunges 10° NW. The fold is tight in the area between Coal Creek and Palmer Junction.

The Cyclone Creek syncline and the West Twin Creek anticline trend northwestward from the White River. They are not traceable in the area between Grass Mountain and Eagle Gorge. The Cyclone Creek syncline plunges about 15° NNW. The West Twin Creek anticline plunges an estimated 15° NW. It is probably the northwestward continuation of the Chinook Pass anticline (Fiske, 1960, pl. 1). These folds are offset by the northwestward-trending Twin Creek fault.

The Colquhoun syncline and Sawmill Creek anticline are so gentle that they are not traceable along the northern slope of Huckleberry Mountain.

The Mount Washington anticline plunges an estimated 30° SE along the southwestern side of the Cedar River. The fold is not traceable in the Cougar Mountain Formation because in the area south of the Cedar River the rocks are highly contact metamorphosed and are intricately intruded by dikes.

The Mount Catherine anticline trends south-southeastward from north of the map area through Mount Catherine to Lake Keechelus. The fold plunges 30-45° SSE.

The Meadow Mountain anticline is a broad open northwestward plunging fold which extends from Dandy Pass northwestward through

Meadow Mountain. In this area the fold is horizontal; northwest of the mountain it plunges 30° beneath the North Fork of the Cedar River. The fold is traceable northwestward through the contact metamorphic aureole along the southern side of the Snoqualmie batholith. West of Mount Gardner the fold is not traceable in the intensely metamorphosed zone. The fold has been traced for a distance of about 10 miles.

Between Silver Peak and Meadow Mountain along the Cascade crest minor folds trend across the regional southward dip and form structural terraces. East of the crest the folds plunge gently northwestward. They die out in the area between Meadow Creek and Lost Lake. The Mount Baldy anticline is the best exposed of these structures. It is tightly folded at the northwest where it is truncated by Snoqualmie granodiorite. To the southeast it plunges gently toward the crest.

The Hyak anticline plunges about 40° S beneath Lake Keechelus. The Lake Keechelus syncline is poorly exposed in the highway cuts along the east shore of the lake. It plunges about 5° S and underlies the southern part of the lake. The Whittier anticline separates the Lake Keechelus and Cole Butte synclines. It plunges about 20° S beneath the upper Yakima River valley south of Lake Keechelus. The fold is named for the station along the Chicago, Milwaukee, Saint Paul and Pacific Railroad in the SE¼ sec. 22, T. 21 N., R. 12 E., located along the fold. It is probably terminated on the south by the Dandy Pass fault. The Log Creek syncline trends along the Cascade crest and plunges about 10° SE into the drainage basin of Log Creek. Cabin Creek anticline lies between the Log Creek and Cole Butte synclines. It trends northwestward to northward and plunges as steeply as 45° N beneath the upper Yakima River valley. The trace of this fold cannot be clearly delineated in the field. It may be offset locally by minor faults in the area between Cabin Creek and the upper Yakima River valley. Stout (1959, pl. II) delineated the Cabin Creek anticline east of Log Creek.

Faults

General features.--The faults were mapped almost entirely upon stratigraphic evidence. Termination of formational contacts, abrupt changes in bedding attitudes, and local large linear zones of highly fractured rock, especially along the Roaring Ridge fault north of Roaring Creek, were guides for locating faults. The faults cannot be delineated on the basis of topographic evidence. No major fault contacts were located in the field. Consequently, the attitudes of the fault planes is uncertain. Their relationship to the topography suggests that they are high-angle. They are interpreted in the structure cross sections (pl. 2) as dipping 90°. Only the faults with a measureable stratigraphic displacement in excess of 100 feet are shown on the map (pl. 1).

Twin Creek fault.--The Twin Creek fault trends northwestward along the north side of White River, in the south-central part of the map area, for a distance of about 3½ miles. It is not traceable east of Twin Creeks or northwest of Cyclone Creek because the fault separates rocks of similar lithology in these areas. It may trend northwestward into the Grass Mountain pluton. The north side has been dropped down. The vertical stratigraphic displacement is estimated to be 1,000 feet (pl. 2 D-D').

Lemolo fault.--The Lemolo fault strikes northwestward along the north side of the Green River between Palmer Junction and Eagle Gorge, in the west-central part of the map area. The fault was first delineated by Warren and others (1945). It has been traced northwest into the Cumberland quadrangle by H. D. Gower (personal communication, June, 1961; Preliminary Geologic Map of the Cumberland Quadrangle, King County, Washington: Wash. Div. Mines and Geol., in press). It extends for a distance of 8½ miles in the map area. The fault probably connects with a branch of Piling Creek fault system north of Eagle Gorge. It has an average stratigraphic displacement of 4,500 feet horizontally and 8,000 feet vertically determined by the offset between the outcrops of the contact of the Eagle Gorge Andesite with the Huckleberry Mountain Formation. The north side has been uplifted and/or moved eastward with respect to the south side.

<u>Piling Creek fault zone</u>.--The Piling Creek fault zone is named for the branching fault zone which trends northwestward in the area between Boundary Creek and the North Fork of the Green River in the northwestern part of the map area. The three branches of the fault zone join northwest of the North Fork of Green River and trend northwestward into the Hobart quadrangle where the fault has been delineated as the Hobart fault.by Vine (1962b). The fault zone has a length of at least 15 miles. To the southeast the fault zone merges with the Green River syncline and Snowshoe Butte anticline. The stratigraphic displacement is greater than 2,000 feet along the southern branch, about 1,000 feet along the middle branch, and estimated to be 1,500-2,000 feet along the northern branch (pl. 2 B-B'). The total stratigraphic displacement along the fault near Barneston may be several thousand feet. Movement along the fault zone has resulted in the uplift of a block between the northern and southern branches.

<u>Dandy Pass fault</u>.--The Dandy Pass fault trends northwestward along the Cascade crest in the east-central part of the map area. The north side has been dropped. The trend of the fault northwest of Dandy Creek is indefinite. The fault may terminate at the Meadow Mountain intrusive complex, coincide with the synclinal fold along Meadow Creek or trend into the Mount Baldy fold. To the southeast the fault extends along the upper Yakima valley to near Lake Easton. It extends southeastward beyond the map area and probably joins with the fault along the south side of the

Easton Ridge, separating Easton Schist fromthe "Naches Formation" to the south (Stout, 1959, pl. II). The fault is at least 10 miles long in the map area. North of Stampede Pass the fault has a stratigraphic displacement of 4,500 feet (pl. 2 F-F'). To the southeast the horizontal displacement measured along the offset of the Cole Butte syncline is 5,000 feet.

Roaring Ridge fault.--The Roaring Ridge fault extends from Cole Creek southeastward along the east side of the small quartz-pyroxene diorite pluton at Roaring Ridge and along the east side of the upper Yakima valley south of Roaring Creek (pl. 2 E-E', E-E") in the area west of Lake Keechelus. The fault probably extends along the valley and joins the Dandy Pass fault east of Stampede Pass. The fault may extend northwestward to Olallie Meadows although no evidence for a fault was found in that area. The fault has truncated minor tight folds in the Snow Creek and "Naches Formations" along Roaring Creek. The stratigraphic displacement is about 500 feet at the mouth of Roaring Creek. The displacement probably increases to the southeast. The fault is at least 6 miles long.

Minor fault.--A fault trends northwestward near the junction of Snow and Sunday Creeks west of Stampede Pass. The northeast side has been dropped, offsetting the Stampede Tuff. The stratigraphic displacement is about 150 feet. The fault has been traced a distance of 2½ miles.

Structures in the Lake Keechelus area

Geologic sections, plate 2 E-E", F-F', and especially I-I', reveal complex structural relationships in the area of the south end of Lake Keechelus. Section I-I' shows that the Stampede Tuff, which has its greatest stratigraphic thickness on the east shore of the lake, thins abruptly in the central part of the lake. The minor folds near Roaring Creek (pl. 1) trend east-southeastward toward the lake yet do not extend across the lake. Part of the complication is due to the lack of bedrock exposures south of the lake. The Mount Catherine and Hyak anticlines, the intervening syncline and the Lake Keechelus syncline plunge southward under the lake but are not traceable southward. However, the relationships indicate the possibility of a fault extending southward from the east side of the outcrop of sheared Mount Catherine Tuff, located east of Hyak, through the middle of the lake and joining the Roaring Ridge fault beneath the surficial deposits in about sec. 22, T. 21 N., R. 12 E. Foster (1960, pl. 1) placed a fault trending north-northeastward along the east side of the Gold Creek valley. The fault does not extend this far north because the strata of the "Naches Formation" strike northwestward from Rampart Ridge across Gold Creek through Kendall Peak.

Arching of the Cascade Range

Evidence of the late Pliocene arching of the Cascade Range is not well shown in the map area. Absence of Yakima Basalt and only remnants of Ellensburg Formation preclude determination of the precise age and extent of the uplift. The axis of uplift cannot be located in the area. The topographic crest is not necessarily the crest of uplift. The arching has probably been broad and the crest subsequently has been deeply eroded. The elevations at the base of the outcrops of the Ellensburg Formation, described within and adjacent to the map area, increase eastward to Ravens Roost. However, this does not necessarily indicate that the axis of uplift lies east of the present topographic crest. The outcrops are remnants of deposits which accumulated in topographic lows during late Miocene to Pliocene or within slight downwarps preserved since early Pliocene.

Interpretation

The northwestward structural trend in the map area parallels the regional trend in central Washington shown in the Tectonic Map of North America, 1962. The intricate relationship of the folds and faults indicates that the structures are the result of the same stress system. The direction of release in the stress system has been primarily vertical, producing structurally higher blocks resembling the horst-wedges of Pratt (1961, p. 1548). The Newcastle Hills-Tiger Mountain structural high west of the area, and the Thorp Mountain-Cle Elum Ridge structural high, to the east are the major wedges adjacent to the map area. The southeastward-plunging folds north of Chester Morse Lake and Mount Catherine may overlie two other horst-wedges adjacent to the area. The major structural depression in the map area overlies primarily a graben, and the adjacent folds and faults are the adjustment of the strata to the compression in the zones bordering the horst-wedges.

The curved trend of the Lindsay syncline around the southern end of the Snoqualmie batholith may indicate a slight warping of the strata in response to uplift of the pluton during or since its emplacement.

The compressional stress system was active in late Eocene prior to deposition of the Mount Catherine Tuff. The compression may have been initiated earlier; however, evidence to date folding earlier than late Eocene is not present in the map area. The deformation probably has persisted to recent time. In the order of their decreasing intensity, the following periods of deformation have occurred in the map area:

(1) middle Miocene (pre-Yakima Basalt)

(2) late Eocene (pre-Mount Catherine Tuff)

(3) late Miocene to early Pliocene (pre-Ellensburg Formation), and

(4) late Eocene to early Oligocene (pre-Stampede Tuff).

Most of deformation during late Eocene to early Oligocene was the result largely of continued subsidence of the area south of the Green River.

GEOLOGIC HISTORY

1. In the middle (?) and late Eocene a broad flood plain sloping westward existed in the map area. The sea coast lay several miles to the west. The climate was warm and humid. Arkosic and volcanic sediments and lava flows accumulated upon the plain as it gently subsided, accumulation roughly equalling the rate of subsidence so that the area was never submerged by marine waters. The deposits form the Puget Group and the Guye Formation. The arkosic and volcanic sediments are interstratified and were derived from different sources. The arkosic sediments came from a granitic crystalline source north and east of the area. The volcanic detritus and lava flows were derived from an extrusive source which was projected above the flood plain some distance to the west (Crandell and Gard, 1960).

2. In the late Eocene the deposits were deformed and the entire area subjected to erosion. Uplift was greater to the north and east where much of the upper part of the Puget Group was removed. Erosion lowered the area to a low-lying hilly terrain.

3. In the late Eocene extensive sheets of rhyodacite and dacite ash accumulated. They form the Mount Catherine Tuff.

4. Then followed a period of less violent volcanic eruptions, in which a great quantity of lava was extruded from a

source immediately southwest of the area and accumulated within a long north-south trough as a thick succession of lava and breccia flows. These rocks are preserved as the Enumclaw Formation. Fragmental ejecta blanketed the area to the east. They were in part interstratified with arkosic sediments and a few lava and breccia flows. The arkosic sediments were derived, as in Puget time, from a crystalline source to the north and east of the map area. A few lavas, e.g., the Rampart Ridge Porphyry Flows, were derived from scattered sources in the immediately surrounding area. The interstratified arkosic sediments and volcanic rocks are the "Naches Formation." Subsidence of the area was in progress at the same time.

5. Outpourings of large quantities of lavas ceased but were followed by prodigious volumes of fragmental volcanic ejecta derived from probably large explosive volcanic centers lying outside the area. A few lava flows, extruded from local sources, were interstratified with the deposits of ejecta. The accumulation is the Huckleberry Mountain Formation. The rate of outpouring exceeded the rate of subsidence. Irregular, gentle warping of the strata accompanied the subsidence.

6. Probably still in the late Eocene, explosive volcanic activity ceased. Subsidence of the area continued but probably at a rate slower than during Enumclaw and Huckleberry Mountain times.

7. Near the close of Eocene time the area was buried beneath a thick succession of lavas which filled the previously cut valleys. These lavas form the Eagle Gorge Andesite. Mild warping of the area proceeded during the same period.

8. Warping and subsidence continued, especially the latter in the southern part of the area, after cessation of extrusion of the Eagle Gorge Andesite.

9. In the late Eocene or the early Oligocene the area was again blanketed by sheets of dacite ash, forming the Stampede Tuff. The ash was derived from a fissure in the northeastern part of the area, and distributed over the area primarily as ash falls. The ash filled the topographic lows in the area.

10. The dacite ash falls were succeeded by explosive volcanic eruptions and relatively mild upwellings of lavas, which contributed to thick accumulations of fragmental ejecta in the eastern and western parts of the area respectively. These deposits were preserved as the Snow Creek Formation. Gentle warping of the area continued at the same time.

11. Accumulation of volcanic rocks past Snow Creek time may have continued in the area but record of such deposition has been removed by erosion probably in the very early Miocene. The climate during the erosional interval was more temperate than previous, being probably cool and moist.

12. In probably early Miocene time lava flows descended the valleys and were attacked by the streams. Much of the new flow rock accumulated as coarse conglomerates and filled the preexisting valleys. Later flows covered a subdued terrain. The conglomerates and flows constitute the Cougar Mountain Formation.

13. During the middle Miocene the area underwent major deformation, followed by intrusion of hypabyssal porphyries and the emplacement of the Snoqualmie batholith. Deformation did not, however, cease. The major structures within the area were formed during this period. The area was elevated, the northern part to a greater extent, and the total area was subjected to more severe erosion than during earlier Tertiary time. During this erosional period the major drainages were formed.

14. By the beginning of the late Miocene the area was subdued topographically but yet had moderate relief. The Yakima Basalt flows may have extended across the southern part of the area.

15. Deformation of the area occurred again at the end of Yakima time during late Miocene to early Pliocene. The deformation was along the same trends established in the late Eocene and reenforced in middle Miocene. The climate was now temperate, cool to cold and moist. The topography was hilly, of low to moderate relief, not mountainous.

16. In the Pliocene products of andesitic volcanism accumulated as sediments and flows in the topographic lows and probably did not bury the high points of relief. These deposits constitute the Ellensburg Formation.

17. Ellensburg deposition culminated when the Cascade Range was arched, in the late Pliocene. Deformation has probably continued to the present time. The present valleys began to take shape.

18. In the Pleistocene erosion continued to deepen the valleys; alpine glaciation sculptured the high peaks and the westward-flowing rivers were impounded two or more times by large masses of ice which occupied the Puget Sound lowland. The impounding of the rivers resulted in diversion of their courses.

19. Erosion of the area has continued to the present time although the landscape is little modified since the end of the Pleistocene.

APPENDIX A

Stratigraphic Sections

Type section of Mount Catherine Tuff

Location: Center of sec. 22, T. 22 N., R. 11 E., along west side of U.S. Forest Service road about one mile south of Hyak (MC 1).

Mount Catherine Tuff	<u>Feet</u>
Top is concealed by glacial gravel	
19 Crystal-vitric tuff, quartz and feldspar, pale red-purple, eutaxitic layering	50
Top unit (320')	
18 Crystal-vitric tuff, medium-bluish-gray, coarse-grained quartz, speckled with hematite (spec. 2) . .	320
Middle unit (330')	
17 Lithic-pumice crystal-vitric tuff, grayish-red-purple to greenish-gray, scattered ½ mm grayish-red-purple lithic fragments, light-gray flattened pumice fragments, 2 mm long, abundant scattered fine- to coarse-grained prismatic plagioclase and rounded quartz crystals. Lower 5 ft. has abundant cobble-size pumice fragments (spec. 3).	40
16 Pumice crystal-vitric tuff, variegated gray, purple, pale green, pale pink to pale red, a few pale red-purple lithic fragments, abundant pale green pumice fragments, with plagioclase and pyrite crystals, 3 mm long, abundant scattered fine- to coarse-grained rounded quartz crystals; decreases in plagioclase crystals upwards; blocky jointing; well-developed eutaxitic layering	140
15 Covered interval	150
Lower unit	
14 Vitric tuff, light gray, iron oxide-stained, very few quartz crystals, dense, very well-developed eutaxitic layering (spec. 1)	30
13 Covered interval	20
12 Pumice vitric tuff, light gray, very light gray-weathering, abundant flattened pumice; well-developed platy jointing; contains a few dark gray veinlets of quartz	80

		Feet
11	Vitric tuff, light-gray, hematite speckled, scattered flattened pumice, 3 x ½ mm in size, dense, eutaxitic layering, blocky jointing	80
10	Andesite dike, dark greenish-gray, fine-grained, trends N80°E, dipping 70°NW	4
9	Vitric tuff similar to 11; very well fractured, very light-gray weathering; anastomosing veinlets of quartz occur in lower 10 feet	30
8	Covered interval	100
7	Vitric tuff similar to 11	20
6	Covered interval	25
5	Andesite dike, dusky-brown-weathering, fine grained. .	5
4	Vitric light-gray tuff, moderate brown-weathering, few scattered coarse-grained rounded quartz	40
3	Covered interval	120
2	Crystal-vitric tuff, light-gray, quartz-bearing, blocky jointing	75
1	Covered interval	100
Thickness of Mount Catherine Tuff		1,420

Type section of Enumclaw Formation (upper part)

Location: Measured along road in SW¼ sec. 15 and W½ sec. 22, T. 20 N., R. 7 E. (E 1). Top of section lies in the NW¼SE¼SW¼ sec. 22, at the south end of Boise Ridge.

Enumclaw Formation		Feet
Glacial gravel and clay lenses		
13	Breccia flow, rounded fragments, grades downward into pyroxene andesite porphyry flow, dark gray, with zones of preferential weathering, light gray to pale red brown; crude columnar jointing, columns 6 ft. diameter	150
12	Covered interval	600
11	Cyclone Creek Flow Member: pyroxene andesite porphyry flow, medium gray	20
10	Breccia flow, pale blue, pale red purple to pale pink.	120
9	Covered interval	450
8	Breccia flow; flow rock fragments have well-developed plagioclase phenocrysts and are flow-layered	90
	Covered interval	230
7	Pyroxene andesite porphyry flows, pyroxene increases in content upwards; incipient flow layering; platy and crude columnar jointing. Basal flow is 40 ft. thick	120

		Feet
6	Covered interval	1,600
5	Breccia flow, yellowish gray to moderate greenish yellow; abundant chalcedony	120
4	Covered interval	90
3	Andesite porphyry flow, glassy to aphanitic, black; platy jointing; greenish black splotches	85
2	Breccia flow, vesicular aphanitic andesite porphyry fragments, 6 ft. diameter, finer towards top . . .	100
1	Andesite porphyry flow, highly vesicular to scoriaceous, aphanitic; flow layering; chalcedony amygdules; black and less vesicular toward base . .	120
	Covered interval	
	Base is not exposed	
Thickness of Enumclaw Formation		3,895

Stratigraphic section of Enumclaw and Huckleberry Mountain Formations

Location: Along the south side of the Green River valley from Bear Creek westward. Section is measured along logging roads in Bear Creek drainage basin, in the W½ sec. 28 and sec. 29, and along the Northern Pacific Railroad and Weyerhaeuser Company road in the NW¼ sec. 28, S½ sec. 20, N½ sec. 19, SW¼ sec. 18, T. 21 N., R. 8 E., and sec. 13, T. 21 N., R. 7 E.

Base of Eagle Gorge Andesite not exposed

Huckleberry Mountain Formation		Feet
Covered interval		50
24	Interstratified lapilli-tuff and accretionary lapilli-tuff, light brownish-gray to yellowish-gray.	5
23	Covered interval	315
22	Andesite flow	30
21	Lapilli-breccia, green to dusky red; coarse volcanic sandstone at the top	50
20	Andesite flows, dark-gray; massive to flow-layered; platy to blocky jointing; interbreccia zones (spec. 10)	200
19	Covered interval	130
18	Tuff-breccia; abundant dusky red pumice fragments. .	50
17	Tuff-breccia, greenish-gray; intruded by dark-green andesite dike, 25 ft. thick, trending N30°E80°NW . .	55
16	Pumice lapilli-breccia, greenish-gray; intruded by irregular andesite dike, 10 ft. thick	75
15	Covered interval	190

			Feet
14.	Rack Creek Tuff Member Total Thickness		300
	d. Lithic-pumice vitric tuff.	25	
	c. Pumice crystal-vitric tuff, yellow-brown; mottled (see pl. 10B)	75	
	b. Pumice crystal-vitric tuff, olive-gray . .	50	
	a. Crystal-vitric tuff, dark-greenish-gray (spec. 9)	150	
13	Covered interval; a few flows exposed intermittently		400
12	Bear Creek Mudflow Member Total Thickness.		1,300
	h. Mudflow, light-greenish-gray lithic-pumice tuff-breccia; pumice fragments increase in size up to 12 in. at base, flattened . . .	285	
	g. Mudflow, similar to above mudflow; pumice and breccia fragments 12 in diameter at base; abundant carbonized tree fragments .	325	
	f. Lithic tuff-breccia, green	50	
	e. Lithic pumice lapilli-tuff; light-greenish-gray; flattened pumice fragments; scattered carbonaceous fragments	15	
	Shear zone		
	d. Mudflow, lithic-pumice tuff-breccia and pumice lapilli-tuff, gray to light-green; lithic fragments up to boulder in size (see pl. 7A)	150	
	c. Mudflow, lithic-pumice lapilli-breccia, light-green; carbonized tree	75	
	b. Boulder lithic tuff-breccia; fragments up to 3 ft. in diameter	10	
	a. Mudflow, lithic-pumice tuff-breccia, light-green to dark-greenish-gray; lithic fragments up to 4 ft. in diameter	390+	
11	Covered interval		810
10	Tuff-breccia, slabby weathering.		65
9	Aphanite flow, brecciated, dense		30
8	Flow, curved fracture faces; lower 5 ft. is altered		30
7	Covered interval		15
6	Breccia flow		20
5	Lithic tuff-breccia		5
4	Covered interval		310
3	Tuff-breccia; abundant carbonaceous fragments. . . .		15
2	Pyroxene andesite porphyry flow; platy to irregular jointing		15
1	Covered interval, McDonald Point Tuff Member occurs in this interval		390
Thickness of Huckleberry Mountain Formation			1,470

Enumclaw Formation

			Feet
32	Interstratified lava and breccia flows; medium gray, pale green, grayish purple; altered.		100
31	Flow, platy jointing		25
30	Breccia flow, moderate red		10
29	Flow, irregular jointing		20
28	Flow unit Total thickness		60
	d. Vesicular zone	20	
	c. Irregular to platy jointing zone	10	
	b. Platy jointing zone.	20	
	a. Bottom breccia	10	
27	Volcanic sediments		30
26	Saprolite, very dusky red.		1
25	Flow unit Total Thickness		50
	c. Top breccia	15	
	b. Flow, platy to irregular jointing	15	
	a. Breccia flow, 10 ft. blocks	20	
24	Flow, curved platy jointing		15
23	Breccia flow, altered		45
22	Flow, platy jointing		20
21	Covered interval		600
20	Lithic-pumice tuff-breccia, pale green		20
19	Tuff-breccia, grayish red, fissile		5
18	Lithic tuff-breccia, pale green		20
17	Tuff, fine, pale green to light-gray, fissile		5
16	Lithic tuff-breccia, grayish red		5
15	Covered interval		40
14	Flow unit Total thickness		70
	c. Breccia flow, altered	20	
	b. Flow, irregular jointing	30	
	a. Breccia flow, grayish green, rounded fragments	20	
13	Flow, andesite porphyry		5
12	Covered interval		390
11	Flow unit Total thickness		25
	b. Flow, blocky jointing	20	
	a. Bottom breccia	5	
10	Saprolite, very dusky red		1
9	Lithic tuff-breccia (mudflow), dusky yellow green; fine cobble to boulder size fragment; altered.		110
8	Pumice crystal tuff-breccia, plagioclase crystals, soft, deeply weathered		50
7	Covered interval		470
6	Flow unit Total Thickness		60
	a. Pyroxene andesite porphyry flow, brownish black to dark greenish gray; blocky jointing	60	

			Feet
5	Saprolite, very dusky red		3
4	Flow unit Total thickness		160
	c. Breccia flow, grayish green, grayish red towards top	40	
	b. Flow, brownish black, blocky to irregular jointing	40	
	a. Breccia flow, grayish green, grayish red towards bottom	40	
3	Flow, blocky irregular jointing		30
2	Covered interval		180
1	Interstratified breccia flows, grayish green, medium gray, yellowish gray; zeolitic; 2-foot interbeds of pale green lapilli-tuff		335
	Covered interval		
Thickness of Enumclaw Formation			4,560

Stratigraphic section of lower part of Huckleberry Mountain Formation and upper part of "Naches Formation"

Location: Blowout Mountain and along the ridge to the southeast. Section starts atop Blowout Mountain in the NE¼NE¼NE¼ sec. 14, T. 19 N., R. 12 E., and extends southeastward to the saddle in the NW¼NE¼SW¼ sec. 18, T. 19 N., R. 13 E.

Huckleberry Mountain Formation		Feet
Top of Blowout Mountain		
26	Pumice tuff-breccia, brown; massive; slabby weathering	65
25	Pumice tuff-breccia, green	60
24	Lithic-crystal tuff-breccia, yellowish-gray; grades upward into crystal tuffin upper 10 ft.	55
23	Lithic tuff-breccia, massive, light-gray to grayish-blue; crystal and vitric constituents increase and lithic fragments decrease upwards	20
22	Lapilli-tuff, grayish-yellow-green to green	30
21	Pyroxene andesite porphyry flows, grayish-black; consists of 2-3 flow units (see pl. 10B)	45
20	Crystal tuff, brownish-black, massive, concretionary weathering	10
19	Crystal tuff, dusky green, soft	5
18	Pumice tuff-breccia, dusky green	50
17	Volcanic sandstone, olive-gray to yellowish-gray, thin-bedded.	10
16	Pumice tuff-breccia, light-green	30

		Feet
15	Crystal-vitric tuff, light-green to greenish-gray	20
14	Crystal-pumice tuff-breccia, green, brown-weathering massive; slabby weathering in upper 15 ft.	50
13	Unmeasured interval on northeast side of Blowout Mountain from saddle to north of mountain to pond below	600±
12	Pyroxene andesite porphyry flow, black; vesicular zone at base; columnar jointed; breccia flow caps unit. Flow unit caps southeast ridge	25
11	Crystal-pumice tuff-breccia, massive; coarser flow rock fragments occur near top	60
10	Interstratified fine tuff, crystal tuff, and lapilli-tuff	20
9	Tuff-breccia, brown, massive; concretionary weathering; vesicular flow rock fragments; angular pumice fragments 2 in diameter; wood fragments occur at 40 ft. above base	60
8	Saprolite zone, dusky red	½
7	Interbedded crystal tuff-breccia and pumice lapilli-tuff, massive; thin- to thick-bedded; fine tuff at top	45
6	Interbedded fine and coarse crystal tuff, pale greenish-yellow to olive; fine tuff is flinty	75
5	Vesicular andesite flow, brown-weathering; locally brecciated; chalcedony fillings in geodes	10
4	Tuffaceous sandstone, pale olive, coarse-grained, thin-bedded	15
3	Tuff-breccia, yellowish-gray; deeply weathered . . .	30
2	Crystal-vitric tuff, olive-gray, brown-weathering; massive	15
1	Interbedded lapilli-tuff and coarse-grained tuffaceous sandstone, yellowish-gray; gray-weathering; leaf fossils occur at 20 ft. above base (see Appendix C)	65
	Thickness of Huckleberry Mountain Formation (lower part)	1,325

"Naches Formation" (upper part)

		Feet
9	Crystal-pumice tuff-breccia, pale grayish green; consists of 2-3 units of air-fall detritus; gray zone in upper 25 ft. is approximate stratigraphic interval of Blowout Mountain Flow Member; 15-ft. zone of yellowish-gray tuff occurs at base	160

		Feet
8	Porphyritic andesite flows, "felsitic," dusky red; blocky jointing	95
7	Pumice crystal-vitric tuff, very light-gray	15
6	Pumice-crystal tuff-breccia, green	80
5	Porphyritic andesite flows; dark-green; vesicular. .	50
4	Crystal tuff-breccia	15
3	Volcanic sandstone, light-gray; tuff occurs at top .	150
2	Interstratified tuffaceous sandstone; siltstone and tuff	100
1	Interstratified black micaceous siltstone and gray tuffaceous sandstone	20+
Measured Thickness of "Naches Formation"		685

Type section of Stampede Tuff

Location: Along Sunday Creek west of Stampede Pass in the NW¼ sec. 25, T. 21 N., R. 11 E. The base of the formation is exposed along the road about ¼ mile west of the pass in the NW¼SE¼NW¼ sec. 25 (ST 1; see pl. 19).

		Feet
Snow Creek Formation		
	Lithic volcanic sandstone, grayish-green	6
Stampede Tuff		
8	Zone 4. Lithic crystal-vitric tuff, yellowish-gray.	15
7	Covered interval	25
6	Zone 3. Crystal-vitric tuff, light greenish-gray; scattered ¼-½ in. angular grayish-green pumice fragments	25
5	Covered interval	160
4	Crystal tuff, olive-gray	10
3	Covered interval	100
2	Pumice crystal-vitric tuff, light-gray to pale olive; 1-6 in. compressed pumice fragments; good eutaxitic layering	70
1	Pumice breccia, greenish-gray	20
Thickness of Stampede Tuff		425
Huckleberry Mountain Formation		
Volcanic sediments, volcanic sandstone and lapilli-breccia, variegated		

Type section of Snow Creek Formation

Location: Along the north side of the U.S. Forest Service road, about 1½mile west of Stampede Pass, in the SE¼NW¼NE¼ sec. 35, T. 21 N., R. 11 E. (SC 1).

Unit	Snow Creek Formation		Feet
14	Sunday Creek Tuff Member		80+
	e. Lithic-pumice-crystal lapilli-breccia, moderate blue-green to olive-gray	15	
	d. Upper vitrophyre zone. Black crystal-vitric tuff, columnar-jointed.	6-20	
	c. Pumice-crystal tuff-breccia, light-green	10-40	
	b. Lower vitrophyre zone, thins to north. ...	4	
	a. Lapilli-tuff, green	4	
13	Crystal-vitric tuff, greenish-gray		6
12	Lithic tuff-breccia, boulder size fragments; abundant carbonaceous fragments at base; mudflow		40-75
11	Tuff, yellowish-gray to greenish-gray; well-bedded .		1
10	Tuff, dusky red to light olive-gray		4
9	Lapilli-tuff, yellowish-gray; soft		1
8	Interstratified yellowish-gray volcanic sandstone and dusky red laminated siltstone; slumped bedding (see pl. 7B)		1
7	Interstratified tuff, lapilli-tuff, volcanic sandstone, yellowish-gray		1½
6	Lapilli-tuff, yellowish-gray; well-indurated		1
5	Interstratified, fine- to coarse-grained volcanic sandstone, dusky red to green		6
4	Interstratified lapilli-tuff and tuff, yellowish-gray to greenish-gray		2
3	Tuff, olive-gray		1½
2	Lapilli-tuff, yellowish-gray		2
1	Interstratified lapilli-tuff, dusky red to light-green		
	Base not exposed		
	Thickness of Snow Creek Formation		182+

Stratigraphic section of "Naches Formation"

Location: Along the north side of U.S. Highway 10, about 5 miles northwest of Easton. Section starts in the NW¼SE¼NW¼ sec. 31 and extends into the NW¼ NW¼SW¼ sec. 37, T. 21 N., R. 13 E. (N 4).

"Naches Formation"			Feet
61	Rampart Ridge Porphyry Flow Member		510+
	c. Andesite flows, dark greenish-gray; amygdaloidal; porphyritic toward top	400+	
	b. Andesite flow, amygdaloidal. Has a 10-ft. breccia at top	60	
	a. Lower porphyry flow, greenish-black	50	
60	Covered interval		75
59	Andesite flows, olive-gray; amygdaloidal		300
58	Covered interval		450
57	Andesite flow, greenish-gray; amygdaloidal toward top		30
56	Micaceous volcanic sandstone, greenish-gray to medium light-gray; thin-bedded		10
55	Sandstone, light-gray; fine-grained		6
54	Andesite flow, greenish-gray; amygdaloidal toward top		20
53	Porphyritic andesite flow, dark gray to dark greenish gray; upper 5 ft. is breccia		70
52	Andesite flow, dark gray; columnar-jointed; a few amygdules		40
51	Andesite flow, dark gray; vesicular		20
50	Covered interval		400
49	Andesite flow, medium gray; vesicular and amygdaloidal toward top		150
48	Volcanic sandstone, light olive-gray to greenish-gray; thin-bedded		35
47	Andesite flow, medium gray; vesicular and amygdaloidal in upper 15 ft.		50
46	Volcanic sandstone, light olive-gray to light-gray, fine-grained		10
45	Covered interval - small creek		100
44	Volcanic sandstone, light olive-gray tolight-green		20
43	Tuff, green, fine-grained		3
42	Micaceous sandstone, light-gray, coarse-grained		7
41	Tuff, light-green		3
40	Micaceous arkosic sandstone		3
39	Micaceous tuffaceous sandstone, light greenish-gray.		4
38	Sandstone, light-gray, coarse-grained		30
37	Interstratified tuff and volcanic sandstone, medium light-gray		20

		Feet
36	Tuffaceous sandstone, medium gray to brown; poorly exposed	25
35	Lithic arkosic sandstone, light-gray, coarse-grained	10
34	Carbonaceous siltstone	2
33	Interstratified volcanic sandstone, fine- to coarse-grained, greenish-gray	60
32	Volcanic sandstone, light olive-gray, fine-grained	6
31	Tuff, light olive-gray	1
30	Lithic arkosic sandstone, light-gray, coarse-grained	15
29	Volcanic sandstone, olive-gray	3
28	Arkosic sandstone, light olive-gray to medium-gray, angular clay galls	30
27	Volcanic sandstone, dark greenish-gray	2
26	Sandstone, light olive-gray to medium gray, coarse-grained with tuff interbeds	10
25	Siltstone, light olive-gray	4
24	Arkosic sandstone, light-gray, coarse-grained.	10
23	Covered interval	5
22	Lithic micaceous arkosic sandstone, medium light-gray, with light olive-gray micaceous siltstone interbeds	30
21	Micaceous arkosic sandstone, dark-gray	5
20	Covered interval	10
19	Tuff, carbonaceous	3
18	Basalt flow, brecciated, dark greenish-gray	45
17	Pyroxene andesite porphyry flow, dark greenish-gray.	10
16	Interstratified fine- to coarse-grained volcanic sandstone, gray to green; few carbonaceous layers.	25
15	Lithic pumice crystal tuff, dark greenish-gray	35
14	Interstratified dark green to gray volcanic sandstone, micaceous sandstone and pumicelapilli-tuff.	25
13	Lithic tuff-breccia, greenish gray; few boulders of aphanitic flow rock	40
12	Covered interval	20
11	Tuff, dark-green	3
10	Micaceous siltstone	2
9	Micaceous arkosic sandstone, light olive-gray to gray, coarse-grained	20
8	Covered interval	50
7	Lapilli-tuff, light olive-gray	10
6	Fine pebble chert conglomerate	20
5	Micaceous arkosic sandstone, olive-gray.	4
4	Micaceous siltstone, greenish-gray to light-gray	4
3	Micaceous arkosic sandstone, light-gray, laminated cross-bedded	20

		Feet
2	Covered interval	200
1	Interstratified sandstone, siltstone and conglomerate	150
	Extensive covered interval	
Thickness of "Naches Formation"		3,285

Stratigraphic section of Cougar Mountain Formation

Location: Along road along north side of North Fork of Green River, at Ghost Point (CM 2). Section starts in NW¼ sec. 11, extends through SW¼ sec. 2 into NE¼ sec. 11, T. 21 N., R. 8 E.

Cougar Mountain Formation		Feet
15	Upper flows: pyroxene andesite porphyry, well-developed columnar jointing; 50-ft. breccia flow at base	1,660
14	Covered interval	100
13	Boulder conglomerate with sandstone interbeds. . . .	150
12	Covered interval	50
11	Boulder conglomerate	50
10	Interstratified sandstone and conglomerate	30
9	Interstratified conglomeratic and clayey sandstone .	50
8	Boulder conglomerate	100
7	Pumice conglomeratic sandstone	20
6	Boulder conglomerate	200
5	Covered interval	100
4	Fine pebble conglomeratic sandstone	50
3	Covered interval	100
2	Breccia flows, light-gray to pale purple	590
1	Basal lava flows	410
Thickness of Cougar Mountain Formation		4,010

APPENDIX B

Locations of Important Outcrops

Puget Group

P 1 NE¼NW¼SW¼ sec. 2, T. 21 N., R. 7 E.

P 2 NW¼SE¼NE¼ sec. 23, T. 21 N., R. 7 E. (Warren and others, 1945)

P 3 NE¼NE¼NE¼ sec. 2, T. 21 N., R. 7 E.

Guye Formation

G 1 SW¼ sec. 36, T. 23 N., R. 8 E.

G 2 S½ secs. 16 and 17, T. 22 N., R. 11 E.

G 3 Secs. 16 and 17, T. 22 N., R. 11 E.

G 4 SE¼ sec. 16, T. 22 N., R. 11 E.

G 5 SE¼ sec. 9 and NW¼ sec. 15, T. 22 N., R. 11 E.

G 6 NW¼ sec. 15, T. 22 N., R. 15 E.

G 7 NE¼ NE¼ NW¼ sec. 11, T. 19 N., R. 16 E., between the Northern Pacific Railroad and U.S. Highways 10 and 97.

Mount Catherine Tuff

MC 1 Center of sec. 22, T. 22 N., R. 11 E.

MC 2 N½ SE¼ sec. 15, T. 22 N., R. 11 E.

MC 3 Sec. 32, T. 23 N., R. 9 E.

MC 4 Sec. 23, T. 21 N., R. 7 E.

MC 5 SW¼SE¼ sec. 15, T. 22 N., R. 11 E.

MC 6 SW¼SW¼ sec. 17, T. 22 N., R. 11 E.

MC 7 NW¼SW¼SW¼ sec. 22, T. 22 N., R. 11 E.

MC 8 Sec. 5, T. 18 N., R. 7 E., Enumclaw (15-min.) quad.

MC 9 Sec. 4, T. 18 N., R. 14 E., Snoqualmie Pass quad.

Enumclaw Formation

E 1 Central part of T. 20 N., R. 7 E., Enumclaw quadrangle. The road is along the southwestern slope of Boise Ridge in secs. 15 and 22.

E 2 Secs. 3, 10 and 11, T. 22 N., R. 8 E.

E 3 E½ sec. 35, T. 23 N., R. 8 E.

E 4 Sec. 10, T. 22 N., R. 8 E.

E 5 Secs. 27 and 34, T. 20 N., R. 8 E.

E 6 T. 21 N., Rs. 8 and 9 E.

E 7 Sec. 31, T. 21 N., R. 8 E.

E 8 SW¼NW¼NW¼ sec. 31, T. 20 N., R. 8 E.

E 9 SW¼ sec. 27, T. 20 N., R. 7 E.

E 10 NW¼NE¼ sec. 34, T. 20 N., R. 8 E.

E 11 N½ sec. 28, T. 20 N., R. 7 E.

E 12 Sec. 24, T. 21 N., R. 8 E., to the center of sec. 30, T. 21 N., R. 9 E.

E 13 Sec. 31, T. 19 N., R. 9 E.

E 14 Secs. 25 and 26, T. 19 N., R. 10 E.

E 15 E½NE¼ sec. 30, T. 19 N., R. 10 E.

E 16 Sec. 35, T. 21 N., R. 7 E.

E 17 NW¼ sec. 19, T. 21 N., R. 7 E.

E 18 W½ sec. 11, T. 20 N., R. 7 E.

E 19 Sec. 29, T. 18 N., R. 7 E.

E 20 Sec. 23, T. 22 N., R. 6 E., Maple Valley quad.

E 21 Sec. 14, T. 23 N., R. 6 E., Maple Valley quad.

E 22 T. 19 N., R. 7 E.

Huckleberry Mountain Formation

HM 1 Secs. 2 and 3, T. 19 N., R. 9 E., secs. 25, 35 and 36, T. 20 N., R. 9 E., and sec. 30, T. 20 N., R. 10 E.

HM 2 SW¼NE¼SE¼ sec. 3, T. 19 N., R. 9 E.

HM 4 secs. 28, 29 and 30, T. 20 N., R. 8 E.

HM 5 Secs. 24 and 26, T. 20 N., R. 8 E.

HM 6 from sec. 9 downstream to the NW¼NW¼ sec. 2, T. 19 N., R. 11 E.

HM 7 Secs. 29, 30 and 32, T. 21 N., R. 9 E.

HM 8 NW¼NE¼NE¼ sec. 35, T. 20 N., R. 8 E.

HM 9 NE¼SW¼NE¼ sec. 28, T. 20 N., R. 8 E.

HM 10 SW¼SE¼NW¼ sec. 20, T. 21 N., R. 8 E.

HM 11 NE¼SW¼NW¼ sec. 16, T. 21 N., R. 8 E.

HM 12 SW¼SW¼NW¼ sec. 27, T. 20 N., R. 8 E.

HM 13 SE¼SW¼NE¼ sec. 30, T. 21 N., R. 9 E.

HM 14 NE¼ sec. 19, T. 21 N., R. 9 E.

HM 15 SW¼ sec. 24, T. 21 N., R. 8 E.

HM 16 NE¼SW¼NW¼ sec. 16, T. 22 N., R. 8 E.

HM 17 SW¼NW¼SE¼ sec. 15, T. 22 N., R. 8 E.

HM 18 SE¼ sec. 20, NW¼ sec. 28 and NE¼ sec. 29, T. 21 N., R. 8 E.

HM 19 NW¼SW¼SW¼ sec. 7,T. 20 N., R. 8 E.

HM 20 SW¼ sec. 29 and NE¼ sec. 32, T. 21 N., R. 9 E.

HM 21 NW¼ sec. 22, T. 22 N., R. 8 E.

HM 22 SW¼ sec. 2, T. 20 N., R. 11 E.

HM 23 SE¼NW¼ sec. 23, T. 22 N., R. 8 E.

HM 24 SE¼NW¼NW¼ sec. 22, T. 22 N., R. 8 E.

HM 25 SE¼NW¼NW¼ sec. 16, T. 21 N., R. 8 E.

HM 26 NW¼NE¼NE¼ sec. 31, T. 21 N., R. 8 E.

HM 27 SW¼NE¼NE¼ sec. 7 and SE¼SW¼NW¼ sec. 18, T. 20 N., R. 8 E.

HM 28 NE¼NW¼SW¼ sec. 11, T. 20 N., R. 9 E.

HM 29 NW¼SE¼SW¼ sec. 3, T. 20 N., R. 9 E.

HM 30 NW¼SW¼SE¼ sec. 36, T. 21 N., R. 9 E.

HM 31 SE¼NW¼SW¼ sec. 28, T. 21 N., R. 8 E.

HM 32 SW¼NE¼SW¼ sec. 27, T. 21 N., R. 8 E.

HM 33 SE¼NW¼NW¼ sec. 33, T. 20 N., R. 10 E.

HM 34 NW¼SW¼SW¼ sec. 24, T. 20 N., R. 8 E.

HM 35 SE¼SW¼ sec. 28, T. 21 N., R. 8 E.

HM 36 NW¼SE¼NE¼ sec. 18, T. 19 N., R. 13 E.

HM 37 SW¼ sec. 11, T. 19 N., R. 12 E.

HM 38 Sec. 9, T. 19 N., R. 11 E.

HM 39 NW¼ sec. 21, T. 19 N., R. 11 E.

HM 40 SE¼SE¼NW¼ sec. 34, T. 20 N., R. 11 E.

HM 41 Sec. 19, T. 22 N., R. 9 E.

HM 42 Center of sec. 6, T. 20 N., R. 13 E.

HM 43 SW¼NE¼SW¼ sec. 27, T. 21 N., R. 8 E.

HM 44 NW¼SW¼SW¼ sec. 24, T. 20 N., R. 8 E.

HM 45 SE¼NW¼NW¼ sec. 22, T. 22 N., R.8 E.

HM 46 SE¼SE¼NW¼ sec. 23, T. 22 N., R. 8 E.

HM 47 SE¼SE¼NE¼ sec. 20, T. 20 N., R. 10 E.

HM 48 SW¼SE¼NW¼ sec. 2, T. 20 N., R. 11 E.

HM 49 NE¼NW¼NW¼ sec. 36, T. 21 N., R. 9 E.

HM 50 NW¼SE¼NW¼ sec. 33 and SW¼NE¼SE¼ sec. 29, T. 21 N., R. 9 E.

Eagle Gorge Andesite

EG 1 Secs. 27, 28, 34 and 35, T. 21 N., R. 8 E., and secs. 1 and 2, T. 20 N., R. 8 E.

EG 2 NE¼NW¼ sec. 33, T. 21 N., R. 8 E.

EG 3 NW¼NE¼NE¼ sec. 12, T. 20 N., R. 8 E.

EG 4 S½ sec. 35, T. 21 N., R. 8 E.

EG 5 NE¼NW¼SE¼ sec. 34, T. 21 N., R. 8 E.

EG 6 Secs. 1 and 2, T. 20 N., R. 8 E.

EG 7 SW¼NE¼NW¼ sec. 22, T. 20 N., R. 8 E.

EG 8 NE¼SW¼ sec. 27, T. 21 N., R. 8 E.

EG 9 S½ sec. 27, T. 21 N., R. 8 E.

EG 10 NE¼NW¼NW¼ sec. 20, T. 20 N., R. 10 E.

EG 11 SW¼SE¼ sec. 36, T. 21 N., R. 8 E.

Stampede Tuff

ST 1 NW¼SE¼NW¼ sec. 25, T. 21 N., R. 11 E.

ST 2 SW¼NW¼NW¼ sec. 25, T. 21 N., R. 11 E.

ST 3 SE¼NE¼SW¼ sec. 26, T. 22 N., R. 11 E.

ST 4 NE¼SW¼NW¼ sec. 22, T. 22 N., R. 8 E.

ST 5 SW¼SW¼SE¼ sec. 35, T. 21 N., R. 11 E.

ST 6 NW¼NW¼NW¼ sec. 1, T. 21 N., R. 11 E.

ST 7 NE¼SE¼NE¼ sec. 34, T. 22 N., R. 11 E.

ST 8 Sec. 22, T. 21 N., R. 12 E.

ST 9 N½ sec. 20, T. 20 N., R. 10 E.

ST 10 NW¼SW¼SE¼ sec. 5, T. 20 N., R. 10 E.

ST 11 NE¼NE¼NW¼ sec. 13, T. 20 N., R. 9 E.

ST 12 SE¼SE¼SW¼ sec. 3, T. 20 N., R. 9 E.

ST 13 SW¼NW¼SW¼ sec. 10, T. 20 N., R. 9 E.

ST 14 NE¼NE¼NW¼ sec. 21, T. 22 N., R. 8 E.

Snow Creek Formation

SC 1 SE¼NW¼NE¼ sec. 35, T. 21 N., R. 11 E.

SC 2 W½ sec. 22, T. 22 N., R. 8 E.

SC 3 NE¼SW¼SW¼ sec. 23, T. 22 N., R. 8 E.

SC 4 SW¼SE¼NW¼ sec. 18, T. 20 N., R. 10 E.

SC 5 NW¼SW¼NW¼ sec. 27, T. 21 N., R. 11 E.

SC 6 SW¼NW¼NE¼ sec. 3, T. 20 N., R. 11 E.

SC 7 NE¼ sec. 22, T. 21 N., R. 11 E.

SC 8 NW¼NW¼SW¼ sec. 13, T. 21 N., R. 11 E.

SC 9 NE¼NE¼SW¼ sec. 14, T. 21 N., R. 11 E.

SC 10 SW¼SW¼NW¼ sec. 32, T. 22 N., R. 11 E.

SC 11 NE¼ sec. 3, T. 20 N., R. 11 E.

"Naches Formation"

N 1 NW¼SE¼SW¼ sec. 35, T. 23 N., R. 11E.

N 2 NW¼ sec. 14, T. 22 N., R. 11 E.

N 3 SW¼ sec. 10, T. 22 N., R. 12 E.

N 4 Secs. 31 and 32, T. 21 N., R. 13 E.

N 5. SE¼ sec. 32, T. 21 N., R. 13 E.

N 6 Secs. 5 and 8, T. 22 N., R. 11 E.

N 7 SW¼ sec. 22 andNW¼ sec. 27, T. 22 N., R. 11 E.

N 8 NW¼ sec. 2, T. 22 N., R. 11 E.

N 9 Center of sec. 26, T. 21 N., R. 12 E.

N 10 NW¼ sec. 34, T. 20 N., R. 13 E.

N 11 Sec. 21, T. 20 N., R. 13 E.

N 12 E½ sec. 30 and W½ sec. 29, T. 20 N., R. 13 E.

N 13 SW¼ sec. 31, T. 20 N., R. 13 E.

N 14 SE¼SE¼ sec. 27, T. 20 N., R. 13 E.

N 15 SE¼ sec. 33 and SW¼ sec. 34, T. 20 N., R. 13 E.

N 16 NE¼SE¼ sec. 33, T. 20 N., R. 13 E.

N 17 SE¼SW¼ NW¼ sec. 10 and NW¼NE¼NE¼ sec. 15, T. 21 N., R. 12 E.

N 18 Sec. 12, T. 22 N., R. 11 E., and W½ secs. 10 and 15, T. 22 N., R. 12 E.

N 19 SE¼NW¼ sec. 8, T. 22 N., R. 11 E.

N 20 NE¼ sec. 11, T. 21 N., R. 11 E.

N 21 Center of sec. 24, T. 21 N., R. 12 E.

N 22 NE¼ sec. 35, T. 21 N., R. 12 E.

N 23 W½ sec. 6, T. 20 N., R. 13 E.

N 24 SW¼NW¼NE¼ sec. 33, T. 21 N., R. 11 E.

Cougar Mountain Formation

CM 1 Secs. 35 and 36, T. 21 N., R. 9 E.

CM 2 Secs. 2, 10 and 11, T. 21 N., R. 8 E.

CM 3 SE¼ sec. 25 and NE¼ sec. 36, T. 21 N., R. 10 E.

CM 4 NE¼SE¼NE¼ sec. 28, T. 22 N., R. 9 E.

CM 5 NE¼NE¼NW¼ sec. 36, T. 22 N., R. 8 E.

CM 6 SW¼NE¼SW¼ sec. 27, T. 22 N., R. 8 E.

CM 7 NE¼NW¼SW¼ sec. 32, T. 21 N., R. 9 E.

CM 8 SE¼NE¼NW¼ sec. 18, T. 21 N., R. 10 E.

CM 9 NE¼SE¼SW¼ sec. 21, T. 21 N., R. 10 E.

CM 10 E½ sec. 20 and W½ sec. 21, T. 21 N., R. 10 E.

CM 11 E½ sec. 20 and W½ sec. 21, T. 21 N., R. 10 E.

CM 12 NE¼NE¼SE¼ sec. 28, T. 22 N., R. 8 E.

CM 13 NE¼SE¼SE¼ sec. 34, T. 22 N., R. 9 E.

CM 14 NW¼NE¼SW¼ sec. 31, T. 22 N., R. 9 E.

CM 15 SW¼NE¼SW¼ sec. 17, T. 21 N., R. 10 E.

CM 16 NE¼SE¼SE¼ sec. 34, T. 22 N., R. 9 E.

CM 17 SE¼SW¼NW¼ sec. 31, T. 22 N., R. 9 E.

CM 18 NE¼SW¼SE¼ sec. 17, T. 21 N., R. 10 E.

CM 19 SW¼ sec. 21 and SE¼ sec. 29, T. 21 N., R. 9 E.

CM 20 Sec. 32, T. 21 N., R. 9 E.

CM 21 NW¼NE¼SW¼ sec. 10, T. 20 N., R. 9 E.

CM 22 Secs. 3 and 4, T. 20 N., R. 9 E.

"Ellensburg Formation"
EB 1 NW¼NE¼SE¼ sec. 35, T. 20 N., R. 8 E.

EB 2 SE¼ sec. 2, T. 18 N., R. 11 E.

EB 3 SE¼NW¼SE¼ sec. 22, T. 18 N., R. 12 E.

Intrusive Rocks
I 1 NW¼NE¼SW¼ sec. 11, T. 20 N., R. 13 E.

I 2 NW¼ sec. 5, T. 20 N., R. 13 E.

I 3 N½ sec. 22, T. 21 N., R. 11 E.

I 4 SE¼ sec. 19, T. 20 N., R. 11 E.

I 5 SE¼SW¼SW¼ sec. 2, T. 20 N., R. 11 E.

I 6 Sec. 3, T. 21 N., R. 10 E.

I 7 NE¼SW¼NW¼ sec. 27, T. 22 N., R. 11 E.

I 8 SW¼SE¼NE¼ sec. 31, T. 22 N., R. 10 E.

I 9 SE¼ sec. 15, T. 22 N., R. 8 E.

I 10 W½ sec. 32, T. 22 N., R. 10 E.

I 11 NW¼ sec. 31, T. 22 N., R. 10 E.

I 12 NW¼ sec. 18, T. 22 N., R. 11 E.

Alteration and metamorphism
A 1 SE¼ sec. 6, T. 19 N., R. 8 E.

A 2 E½ sec. 28 and W½ sec. 34, T. 20 N., R. 8 E.

A 3 SE¼ sec. 27, T. 22 N., R. 9 E.

A 4 Sec. 5, T. 21 N., R. 10 E.

A 5 SE¼ sec. 1 and NE¼ sec. 12, T. 21 N., R. 10 E.

A 6 W½ sec. 16, T. 20 N., R. 8 E.

APPENDIX C

Leaf Fossil Localities

University of Washington localities:

UWA 2300.--Along the access roads to the penstocks above Cedar Falls and below Chester Morse dam, between 1,280-1,480 feet elevation, about 240 feet above the Cedar River on the north side, in the SW¼NW¼ SE¼ sec. 3, T. 22 N., R. 8 E.

UWA 2301.--Along the south side of the logging road spur, between Boulder Creek and the Middle Fork of Taylor Creeks, about ½ mile west of Boulder Creek at 3,240 feet elevation, in the NE¼NE¼NW¼ sec. 36, T. 22 N., R. 8 E.

UWA 2302.--Located on the north side of the Burma Road between Cedar Falls LO and Rattlesnake Mountain, at the second switchback above the LO at 2,200 feet elevation, in the NW¼SE¼SW¼ sec. 32, T. 23 N., R. 8 E., outside of map area.

UWA 2303.--In cut on the west side of the road along the West Fork of Smay Creek, at 1,880 feet elevation, about 3/4 mile north of road junction, in the NW¼SW¼SE¼ sec. 36, T. 21 N., R. 9 E.

UWA 2304.--In cut along the west side of road, located between Seattle Creek and the South Fork of the Cedar River, at 3,400 feet elevation, in the SE¼NW¼NW¼ sec. 9, T. 21 N., R. 10 E.

UWA 2305.--On north side of road north of U.S. Geol. Survey gaging station on East Fork of Smay Creek, at 2,160 feet elevation, 0.1 mile east of road junction, in SW¼SE¼NW¼ sec. 32, T. 21 N., R.10 E.

UWA 2306.--In cut on north side of spur road at 4,000 feet elevation, in the SE¼SW¼NE¼ sec. 15, T. 20 N., R. 11 E. This road is the third level up in the headwaters basin of Intake Creek.

UWA 2307.--In cut on north side of Northern Pacific Railroad, about ½ mile west of Sunday Creek trestle, at 2,560 feet elevation, in the SE¼SE¼SE¼ sec. 34, T. 21 N., R. 11 E.

UWA 2308.--In cut along south side of Northern Pacific Railroad, about midway between gullies at 2,600 feet elevation, in the NW¼SW¼NE¼ sec. 1, T. 20 N., R. 12 E.

UWA 2309.--In cut along south side of Northern Pacific Railroad, about 1/8 mi. north of UWA 2308 and ¼ mi. southeast of abandoned rock cut, at 2,600 feet elevation, in the NE¼SW¼ NE¼ sec. 1, T. 20 N., R. 12 E.

UWA 2310.--In road cut along east side of East Fork of Log Creek, about 3/8 mi. south of road junction and bridge, at 3,360 feet elevation, in NW¼SE¼SW¼ sec. 31, T. 20 N., R. 13 E.

U.S. Geological Survey localities (Wolfe, 1961, p. C-229):

9682 NW¼NW¼ sec. 36, T. 21 N., R. 7 E.

9693 NE¼NW¼ sec. 13, T. 21 N., R. 7 E.

Localities where leaf fossils are available:

NW¼NE¼SE¼ sec. 26, T. 19 N., R. 9 E., south of the junction of the West Fork of White River and the White River, at the base of a thick grayish-white siliceous tuff.

SW¼NE¼SW¼ sec. 17, T. 21 N., R. 10 E., along east side of Seattle Creek in cut along south side of road, at 3,920 feet elevation.

SE¼NW¼NW¼ sec. 23, T. 20 N., R. 11 E., along east side of Intake Creek, in cut along east side of road at 3,120 feet elevation.

SW¼SW¼SE¼ sec. 26, T. 20 N., R. 11 E., exposed along trail on north side of Tacoma Creek at 2,400 feet elevation.

NE¼SE¼NW¼ sec. 22, T. 22 N., R. 11 E., along west side of road about [illegible],300 feet side of Milwaukee ski jump south of Hyak, at 2,720 feet elevation.

SW¼NW¼SE¼ sec. 13, T. 20 N., R. 12 E., in cut on north side of road, along east side of north branch of Cabin Creek, at 3,200 feet elevation.

NW¼NE¼SW¼ sec. 18, T. 19 N., R. 13 E., at end of ridge extending southeast from Blowout Mountain, above bench at 5,040 feet elevation.

SW¼SE¼NE¼ sec. 18, T. 20 N., R. 13 E., on south slope of Cabin Mountain, north of junction between Log and Cabin Creeks, in road cut at 3,920 feet elevation.

NE¼NW¼SE¼ sec. 18, T. 20 N., R. 13 E., on south slope of Cabin Mountain north of junction between Log and Cabin Creeks, in road cut at 3,800 feet elevation.

SE¼NE¼NW¼ sec. 21, T. 20 N., R. 13 E., in road cut along south side of Cabin Creek, about 100 feet east of Cabin Creek bridge, at 2,480 feet elevation.

NW¼SE¼SW¼ sec. 29, T. 20 N., R. 13 E., in road cut south of Cabin Creek, at 3,760 feet elevation.

NW¼NE¼NE¼ sec. 34, T. 20 N., R. 13 E., in road cut southwest of Goat Peak LO, at 4,800 feet elevation.

APPENDIX D

Locations of Specimens and Thin Sections

The field numbering scheme for specimens and thin sections is as follows:

NW 1/4 NE 1/4

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64

SW 1/4 SE 1/4

sec. 10, T.20N., R.8E.

Each square is a quarter of a quarter of a quarter of a section. Specimen 21B-10-20-8 is located in the NW¼SW¼NE¼ sec. 10, T. 20 N., R. 8 E. "B" indicates that at least two specimens were collected in square 21. The material is located in Lot no. 143.

Number in Text	Thin Section and Field Number
Spec. 1	43E-22-22-11
2	R.J. Foster (1957) slide no. 304
3	43B-22-22-11
4	11 -31-20-8
5	44A-24-21-8
6	59 -36-21-7
7	15 -36-21-7
8	27B-20-21-8
9	7A-31-21-8
10	42 -28-21-8

Number in Text	Thin Section and Field Number
Spec. 11	10 -33-20-10
12	41 - 9-19-11
13	47 -26-20-11
14	19 -10-20-11
15	19E-28-21-8
16	24A-34-22-11
17	56 -32-21-9
18	32 -34-22-11
19	44 -26-22-11
20	47 -28-22-8
21	14E-35-21-11
22	14B-35-21-11
23	36 - 6-20-13
24	23B-18-19-13
25 (lower flows)	4A-36-22- 8
26 (upper flows)	52 -23-21- 9
27	26 -31-22- 9
28	62- 2-18-11
29	3 - 5-20-11
30	63 -18-21-11
31	55A-18-21-11
32	13A-15-20-10
33	13A- 5-20-10
34	56B-34-22- 9
35	38 -34-22-10
36	31 -31-22-10
37	9D-32-22-10

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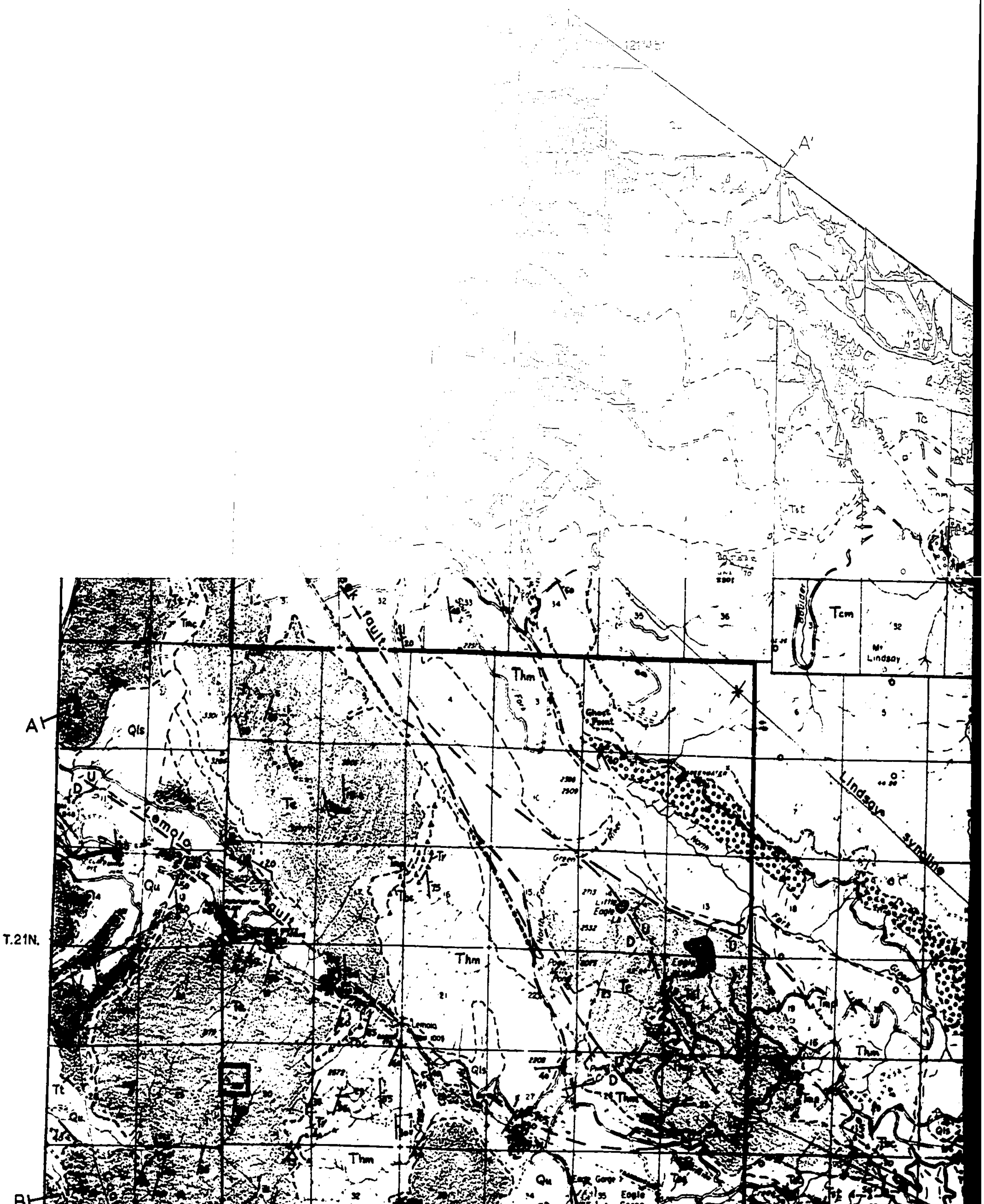
In 1955 he married Jean Anne Marples of Altadena, California. They have three children.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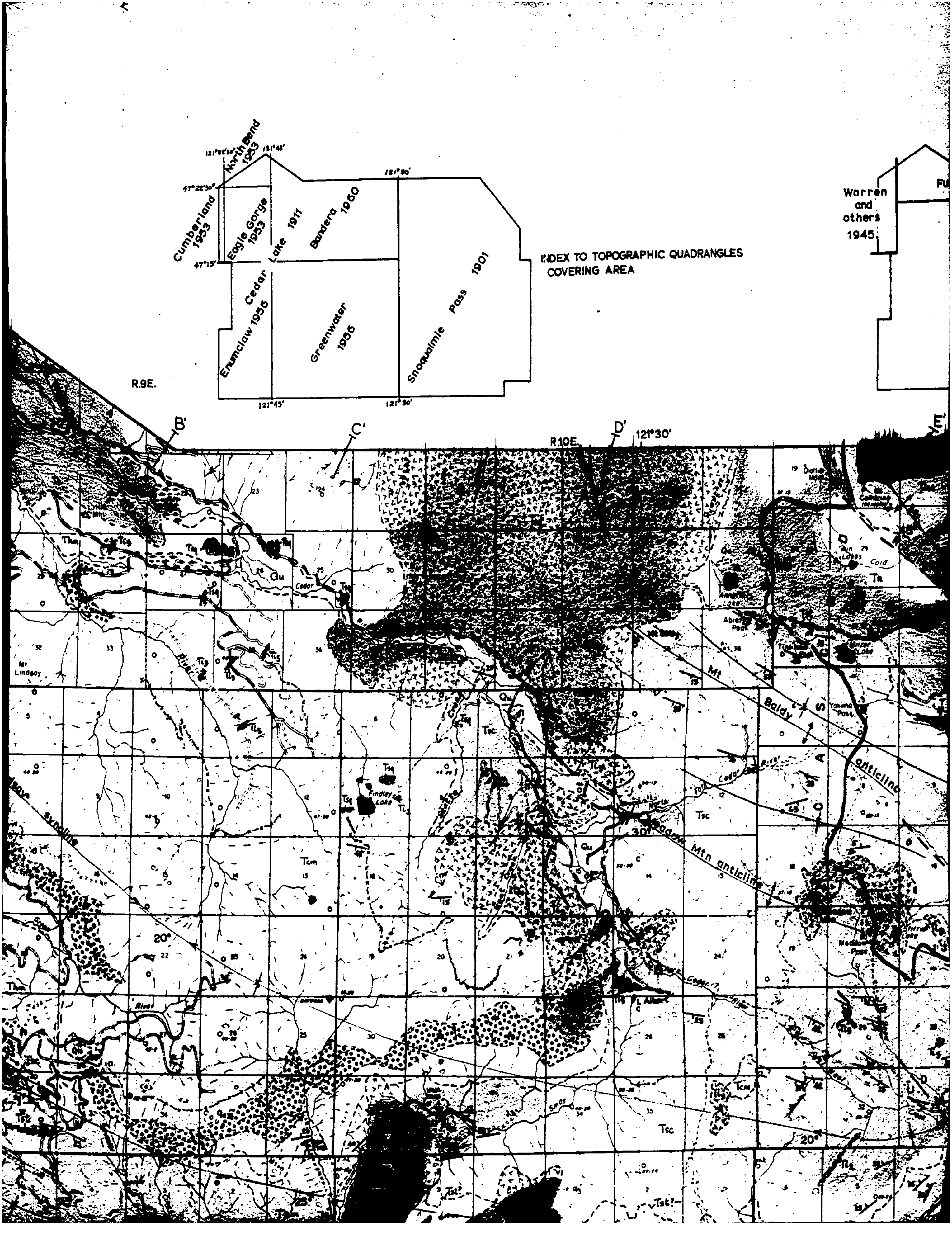
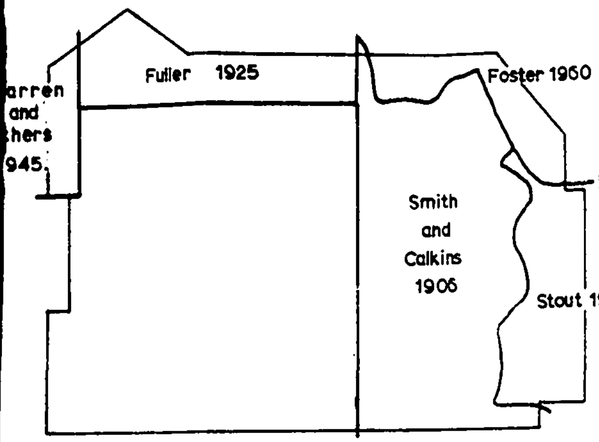
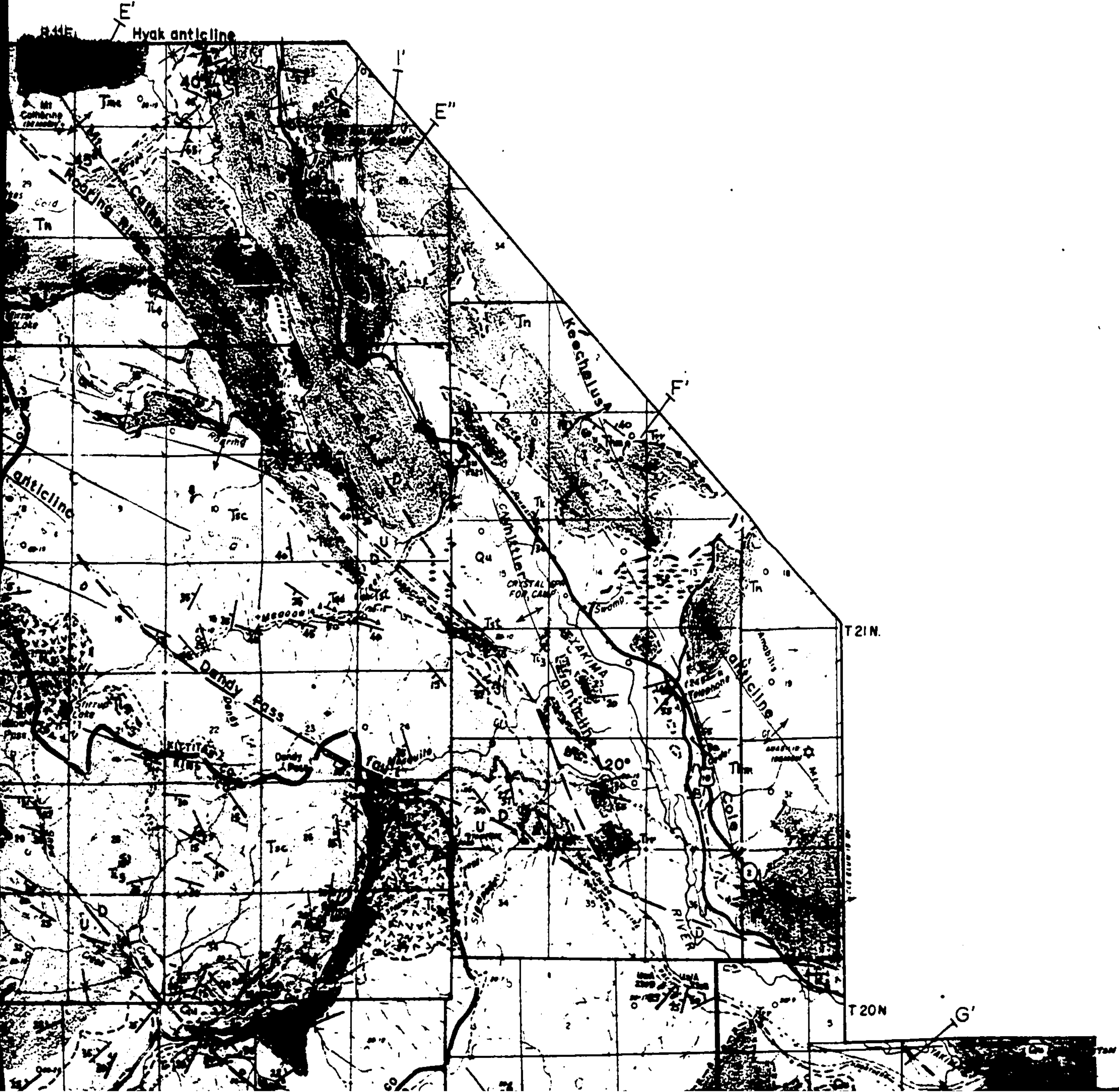
D
U



INDEX TO TOPOGRAPHIC QUADRANGLES COVERING AREA
North Bend 1953
Cumberland 1953
Eagle Gorge 1953
Cedar Lake 1911
Bandera 1960
Snoqualmie Pass 1901
Enumclaw 1956
Greenwater 1956
121°45'
121°30'
47°15'
Warren and others 1945
R.9E.
R.10E.
B'
C'
D'
121°30'
Mt Baldy anticline
Meadow Mtn anticline
syncline
Mt Lindsay
Yakima Pass
Cedar River
Tsc
Tcm
Tsq
Thm
Qu
20°
30°



INDEX TO PREVIOUS GEOLOGIC MAPPING IN AREA



Quaternary
Tertiary
Pliocene
Early (?) Miocene
Oligocene (?)
...chelus Volcanic Group

EXPLANATION

Stratified Rocks

Qls
Landslide

Qu
Quaternary undifferentiated Surficial deposits

erosion surface

definite Teb inferred
"Ellensburg Formation"

unconformity

Tcm
Cougar Mountain Formation

unconformity

Tsc
Snow Creek Formation
Tsd, Sunday Creek Tuff

Tst
Stampede Tuff

unconformity

Teg
Eagle Gorge Andesite

Intrusive Rocks

Andesite

Ti 6
Pyroxene andesite porphyry

definite Ti 5 inferred
Hornblende dacite porphyry

Tsq
Snoqualmie Granodiorite

Ti 4
Quartz-pyroxene diorite

Ti 3
Altered pyroxene-hornblende andesite porphyry

Ti 2
Hornblende lamprophyre

Symbols

CONTACTS

Approximate contact

BEDDING

12 Strike and dip of beds

Horizontal beds

Vertical beds

FOLDS

20° Anticline, showing trace of axial plane, bearing and plunge of axis. Dashed where inferred.

10° Syncline, showing trace of axial plane, bearing and plunge of axis. Dashed where inferred.

FAULTS

U D Fault, approximate location, showing relative movement-U, up, and D, down. Short dashed where inferred.

Fault, in geologic section, plate 2, showing relative movement.

MAPPABLE UNITS

Tuff-breccia

Tuff

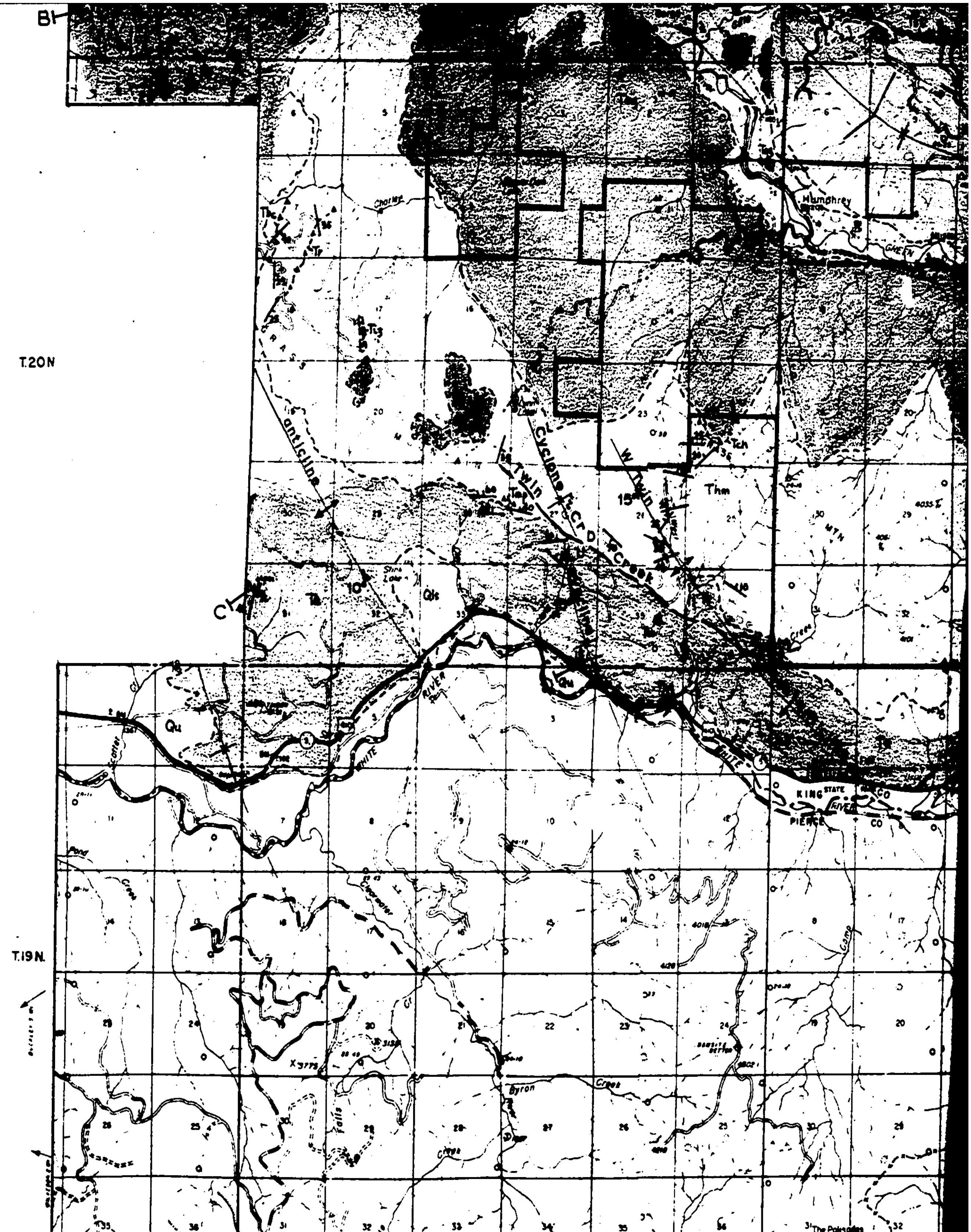
Lava flow

Boulder conglomerate in Cougar Mountain Formation

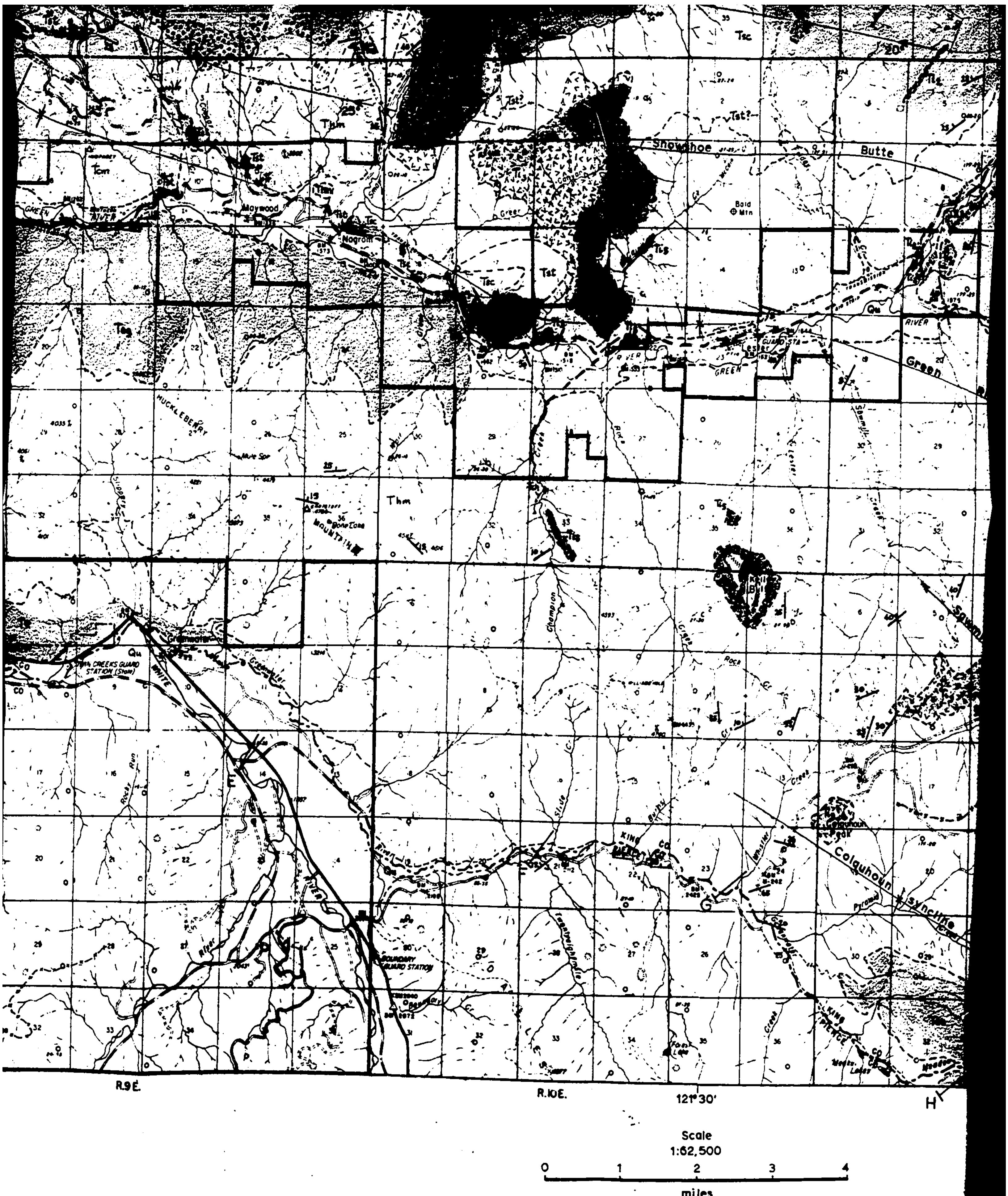
Leaf fossil locality

UWA 2302 Univ. Washington locality

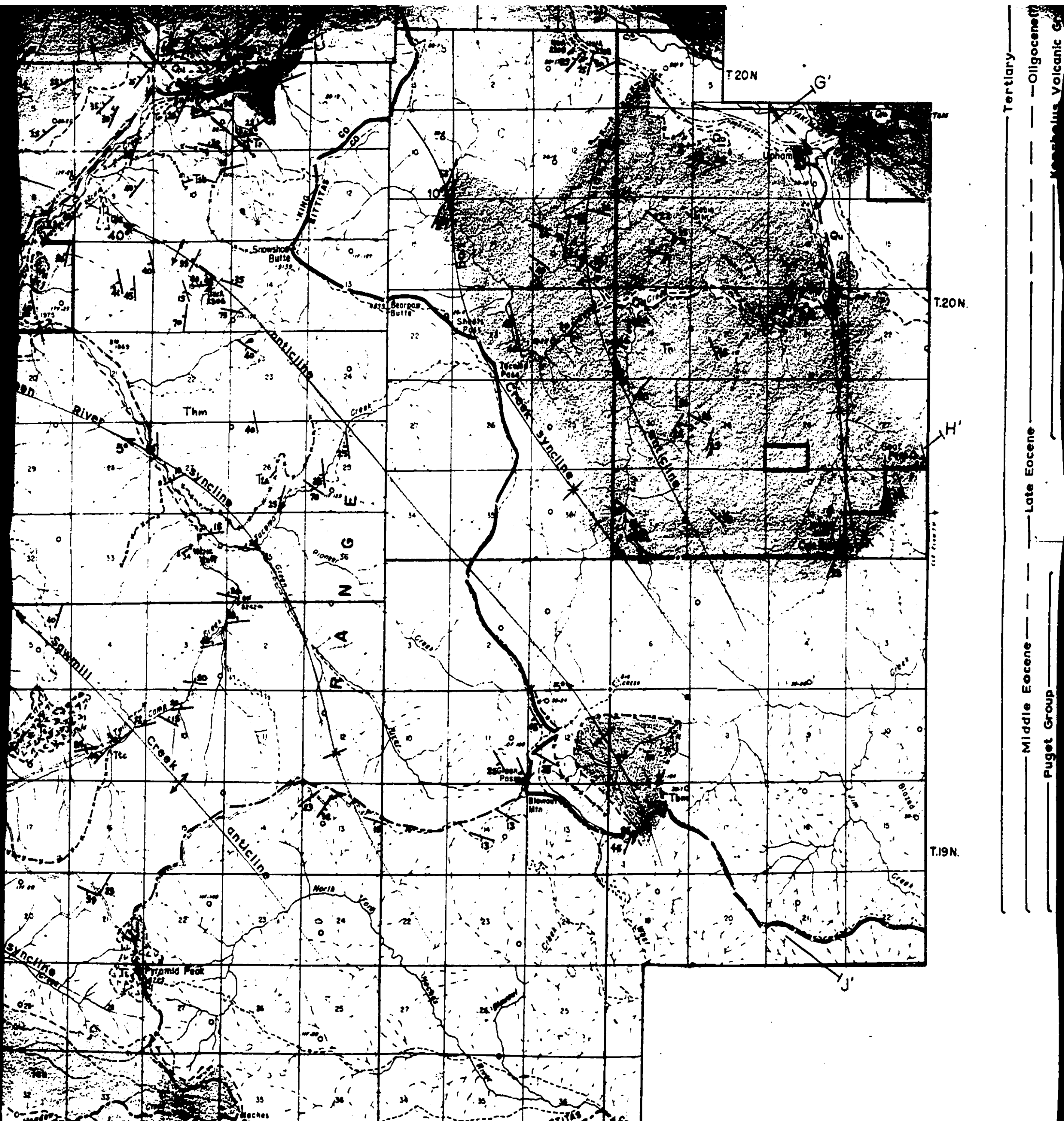
USGS 9862 U. S. Geol. Survey locality (Wolfe, 1961, p. C-229)



Base map from map of North Bend District, Snoqualmie National Forest



RECONNAISSANCE GEOLOGIC MAP OF WEST-CENTRA



Geology by Paul E. Hammond, 1960-62
assisted by Antoni Wodzicki, 1960;
W.S. Rice, 1961, and W.A. Bliton, 1962.

TRAL CASCADE RANGE, KING AND KITTITAS COUNTIES, WASHINGTON

USGS 5862 U.S. Geol. Survey locality (Wolfe, 1961, p. C-229)

Keechelus Volcanic Gr

Teg

Eagle Gorge Andesite

unconformity

Thm

Huckleberry Mountain Formation
Tr, Rack Creek Tuff
Tch, Champion Creek Tuff; Tsb, Snowshoe Butte Flow
Tbc, Bear Creek Mudflow; Tta, Tacoma Creek Flow
Tmp, McDonald Point Tuff; Ttc, Twin Camp Creek Flow

Ti

Altered rhyolite

Te

Enumclaw Formation
Tel, Eagle Lake Flow; Tc, Cyclone Creek Flow

Tn

"Naches Formation"
Tbm, Blowout Mountain Flow; Trr, Rampart Ridge Porphyry Flow
Tk, Kendall Tuff

Tmc

Mount Catherine Tuff

unconformity

Puget Group

Tt

Tukwila Formation

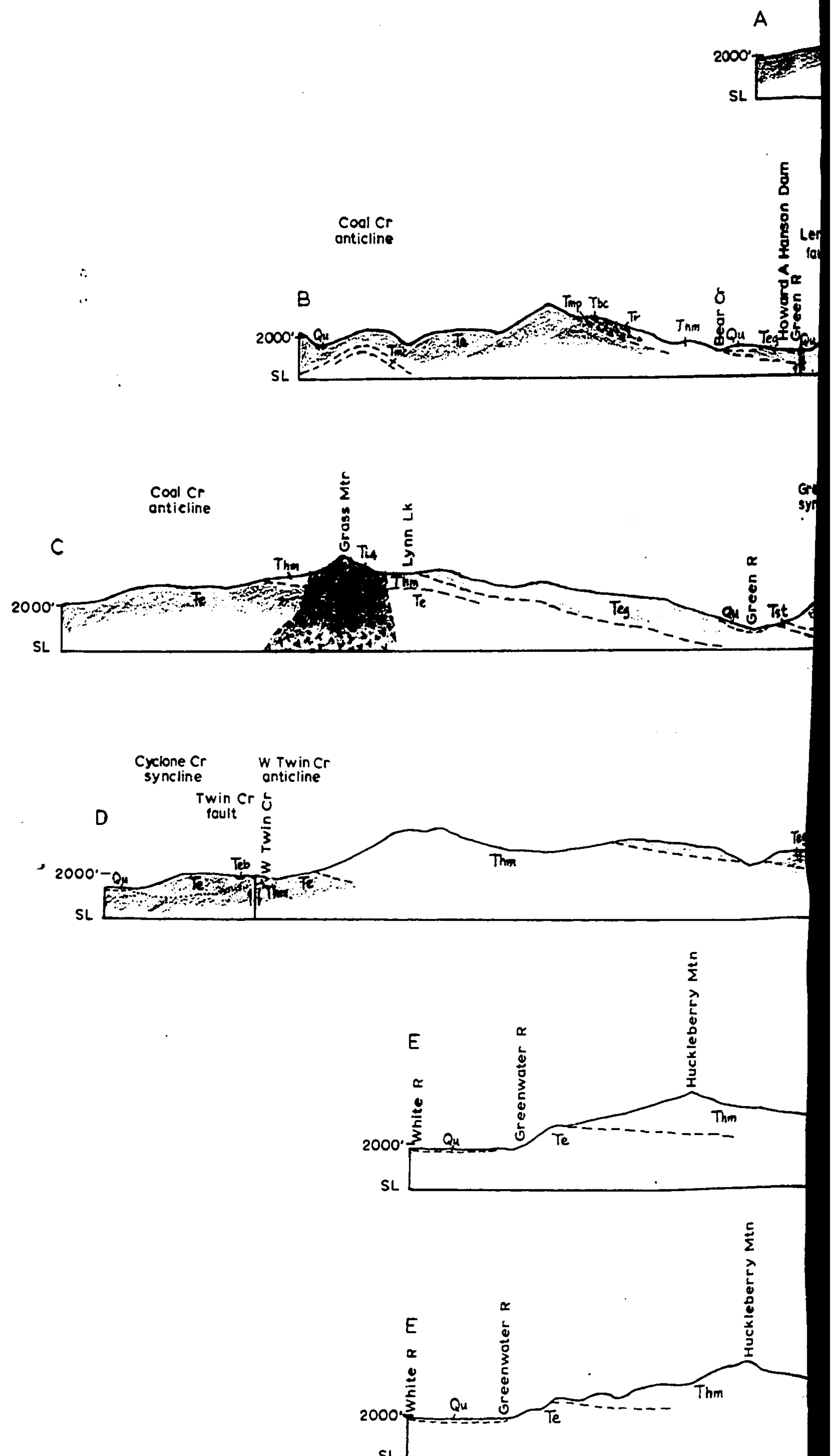
Ttm

Tiger Mountain Formation

Tg

Guye Formation

ON



A
2000'
SL
Coal Cr
anticline
B
Qu
Tmp
Tbc
Tr
Thm
Bear Cr
Teg
Howard A Hanson Dam
Green R
Coal Cr
anticline
C
Grass Mtn
Lynn Lk
Thm
Te
Teg
Green R
Qu
Tst
Cyclone Cr
syncline
W Twin Cr
anticline
Twin Cr
fault
D
W Twin Cr
Teb
E
White R
Greenwater R
Huckleberry Mtn

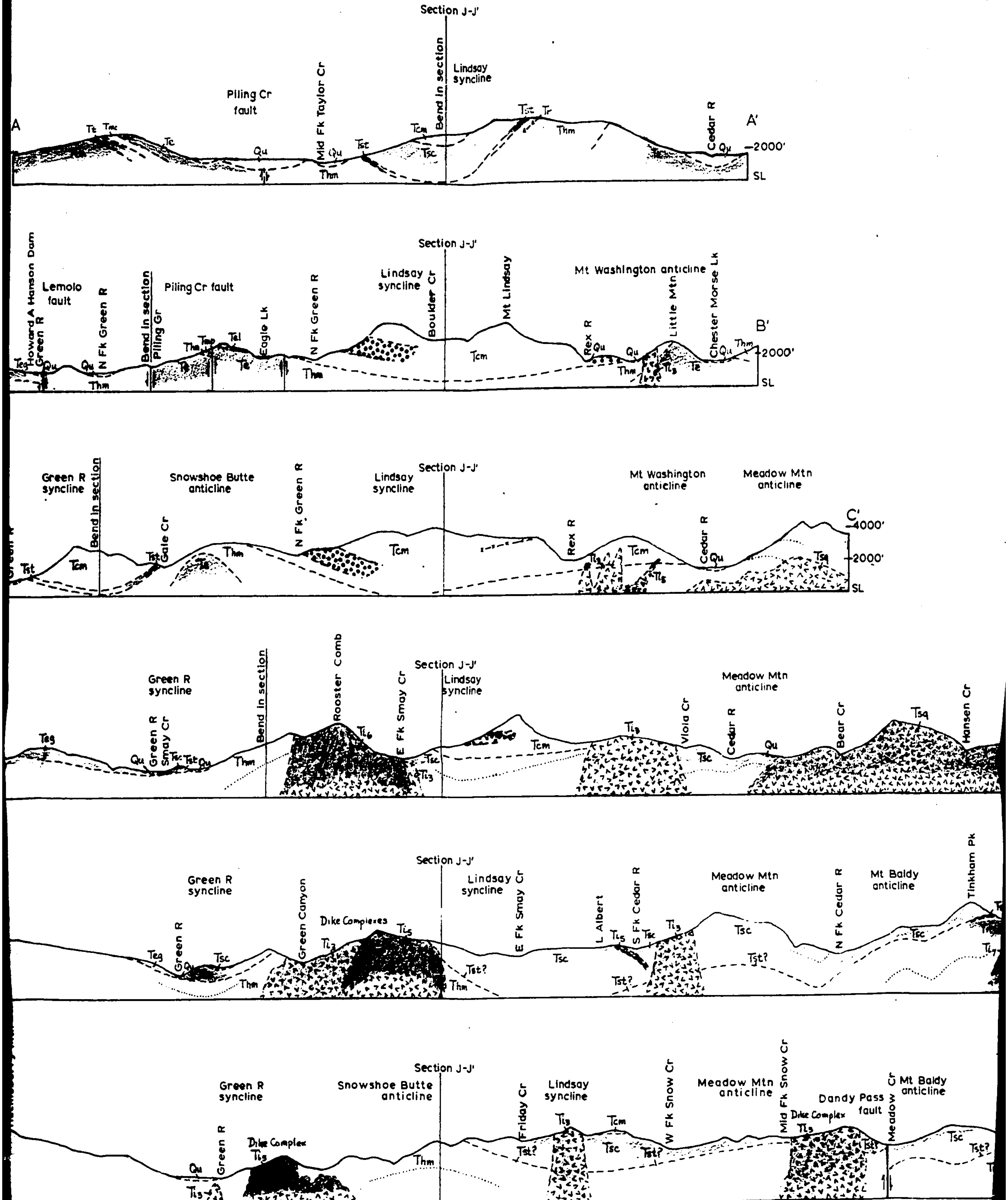
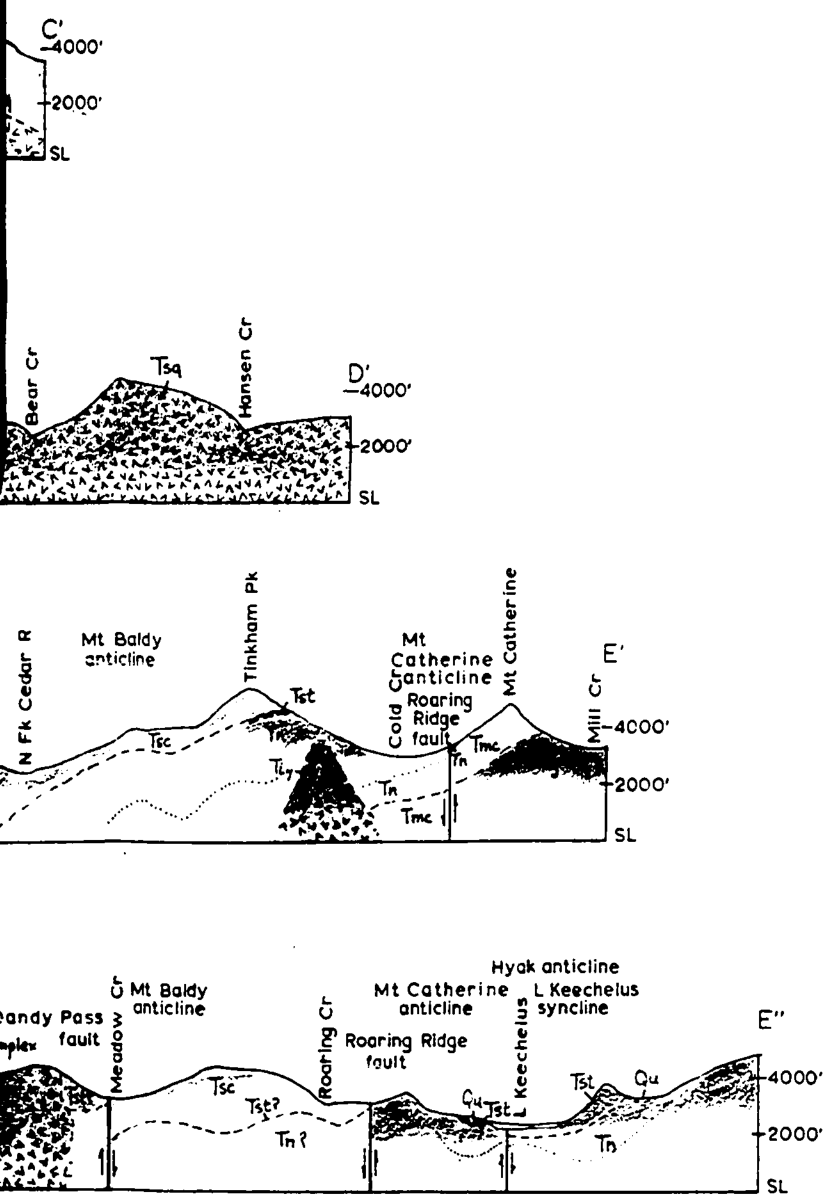
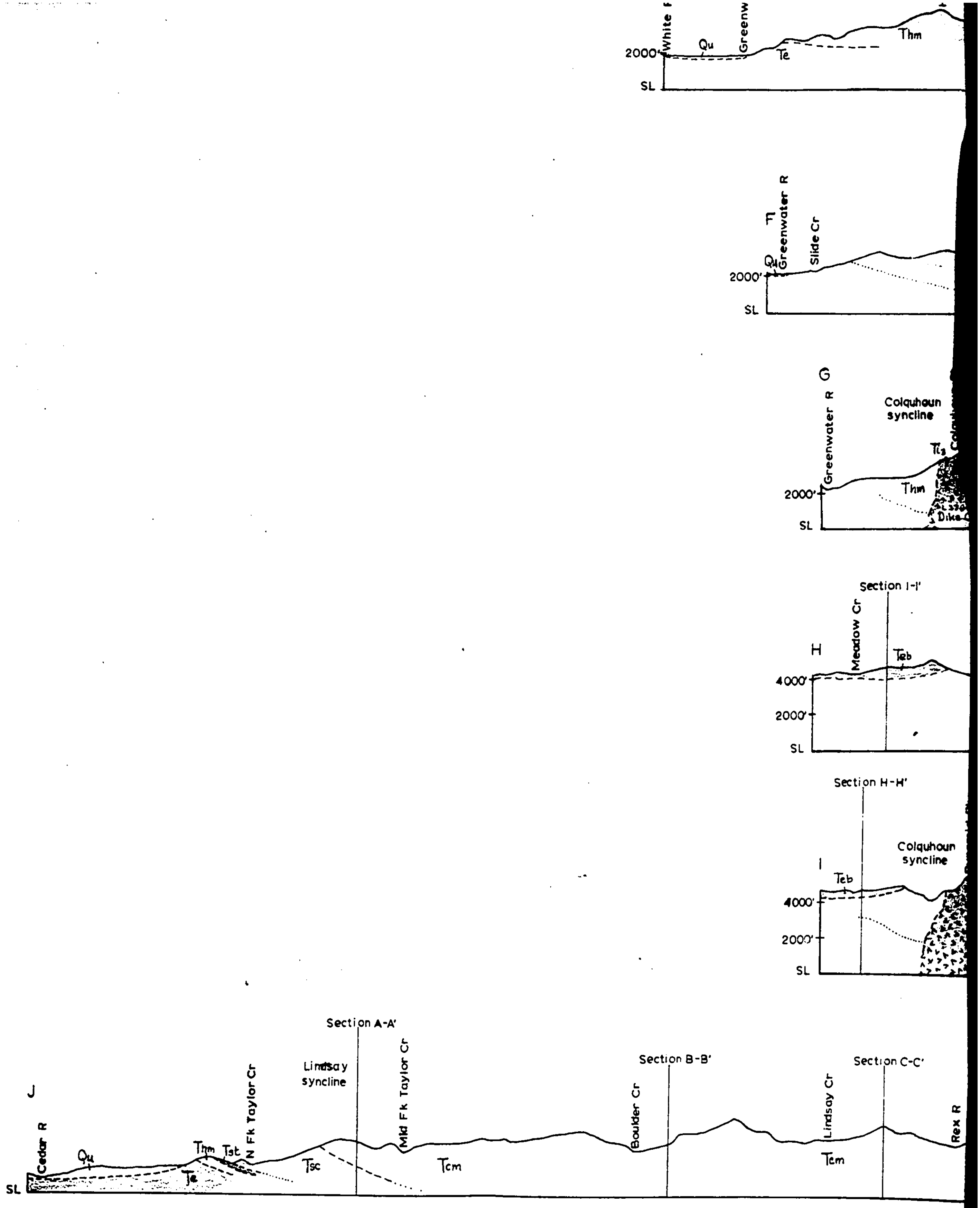

Section J-J'
Bend in section
Lindsay syncline
Piling Cr fault
Mid Fk Taylor Cr
Cedar R
A
A'
-2000'
SL
Qu
Tsc
Tcm
Tst
Thm
Section J-J'
Howard A Hanson Dam
Green R
Lemolo fault
N Fk Green R
Bend in section
Piling Cr
Piling Cr fault
Eagle Lk
N Fk Green R
Lindsay syncline
Boulder Cr
Mt Lindsay
Mt Washington anticline
Rex R
Little Mtn
Chester Morse Lk
B'
2000'
SL
Tcm
Thm
Qu
Section J-J'
Green R syncline
Bend in section
Snowshoe Butte anticline
Gale Cr
N Fk Green R
Lindsay syncline
Mt Washington anticline
Meadow Mtn anticline
Rex R
Cedar R
C'
4000'
2000'
SL
Tst
Tcm
Thm
Qu
Section J-J'
Green R syncline
Green R
Smay Cr
Bend in section
Rooster Comb
E Fk Smay Cr
Lindsay syncline
Meadow Mtn anticline
Viola Cr
Cedar R
Bear Cr
Hansen Cr
Teg
Qu
Tsc
Tst
Thm
Tcm
Tsq
Section J-J'
Green R syncline
Green R
Green Canyon
Dike Complexes
Lindsay syncline
E Fk Smay Cr
L Albert
S Fk Cedar R
Meadow Mtn anticline
N Fk Cedar R
Mt Baldy anticline
Tinkham Pk
Teg
Tsc
Thm
Tst?
Section J-J'
Green R syncline
Green R
Dike Complex
Snowshoe Butte anticline
Friday Cr
Lindsay syncline
W Fk Snow Cr
Meadow Mtn anticline
Mid Fk Snow Cr
Dike Complex
Dandy Pass fault
Meadow Cr
Mt Baldy anticline
Qu
Thm
Tcm
Tsc
Tst?

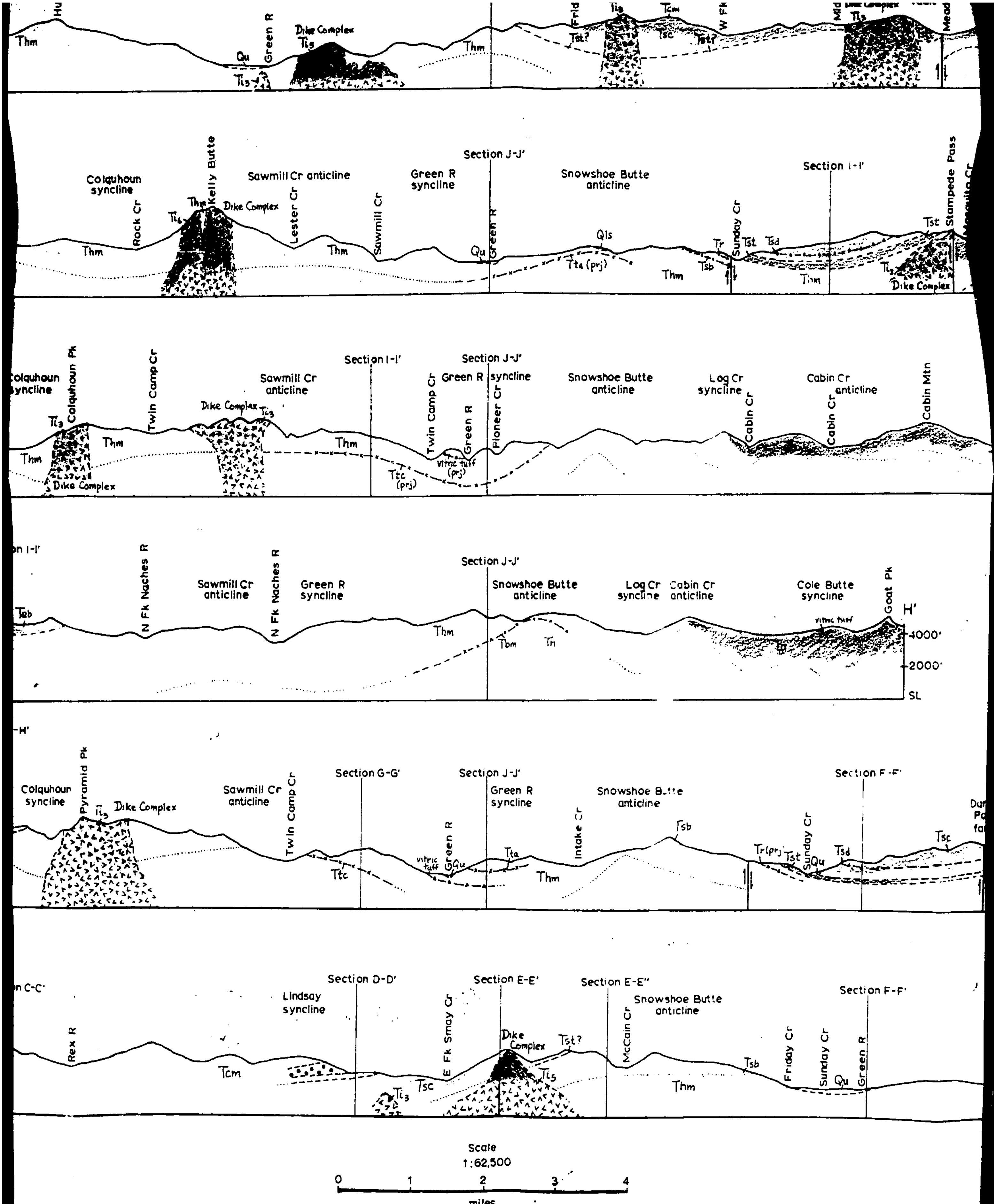
Plate 2


C'
4000'
2000'
SL
Bear Cr
Tsq
Hansen Cr
D'
4000'
2000'
SL
N Fk Cedar R
Mt Baldy
anticline
Tinkham Pk
Tst
Mt
Catherine
anticline
Cold Cr
Roaring
Ridge
fault
Mt Catherine
Mill Cr
E'
Tsc
Tmc
Tn
Tmc
4000'
2000'
SL
Hyak anticline
Mt Baldy
anticline
Mt Catherine
anticline
L Keechelus
syncline
Sandy Pass
fault
Meadow Cr
Roaring Cr
Roaring Ridge
fault
L Keechelus
E''
Tsc
Tst?
Tn?
Qu
Tst
Tst
Qu
Tn
4000'
2000'
SL

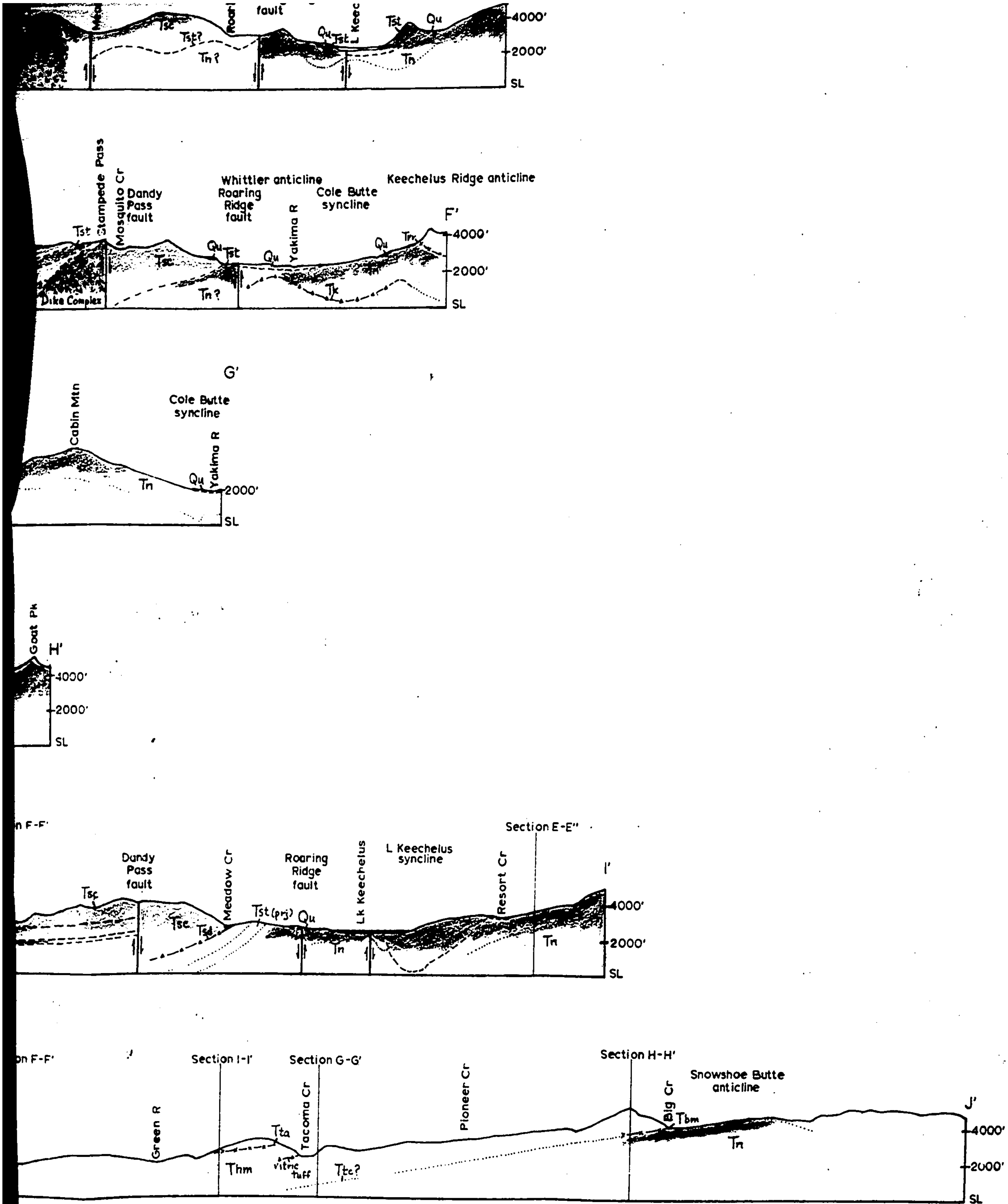


2000'
SL
Qu
Te
Thm
Greenwater R
Slide Cr
2000'
SL
G
Greenwater R
Colquhoun syncline
Thm
2000'
SL
Section I-I'
Meadow Cr
H
Teb
4000'
2000'
SL
Section H-H'
Colquhoun syncline
I
Teb
4000'
2000'
SL
Section A-A'
J
Cedar R
Qu
Thm
Tst
N Fk Taylor Cr
Lindsay syncline
Mid Fk Taylor Cr
Tsc
Tcm
Section B-B'
Boulder Cr
Section C-C'
Lindsay Cr
Tcm
Rex R
SL

GEOLOGI

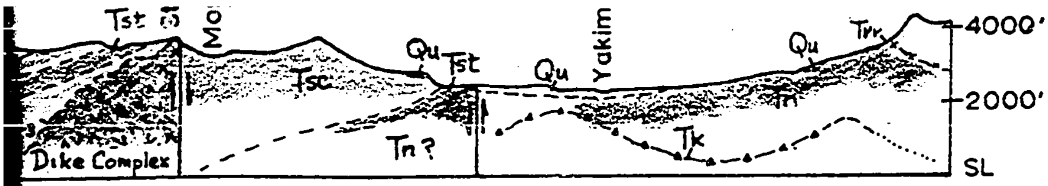


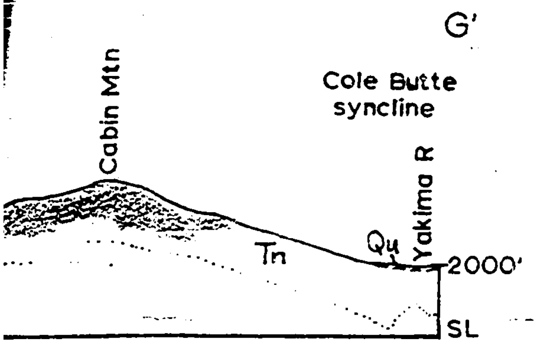
LOGIC SECTIONS OF WEST-CENTRAL CASCADE RANGE, WASHINGTO

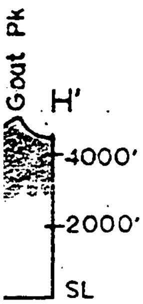


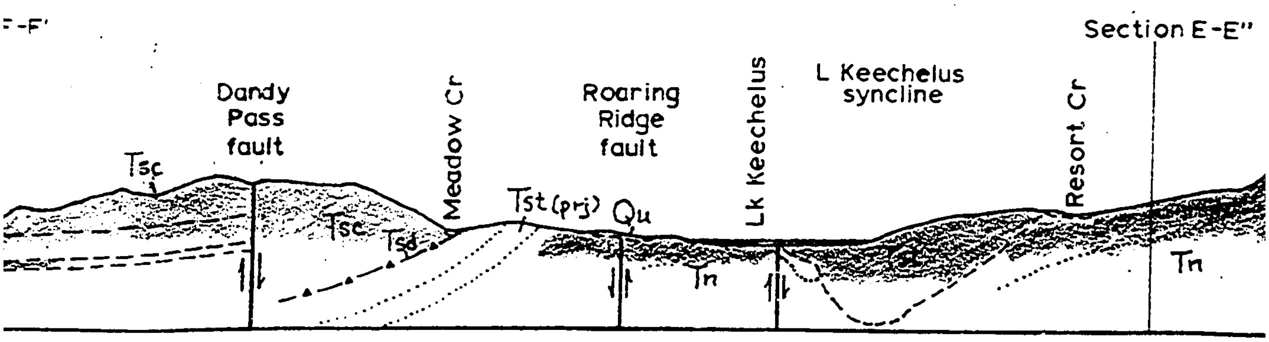
For explanation of symbols see plate 1

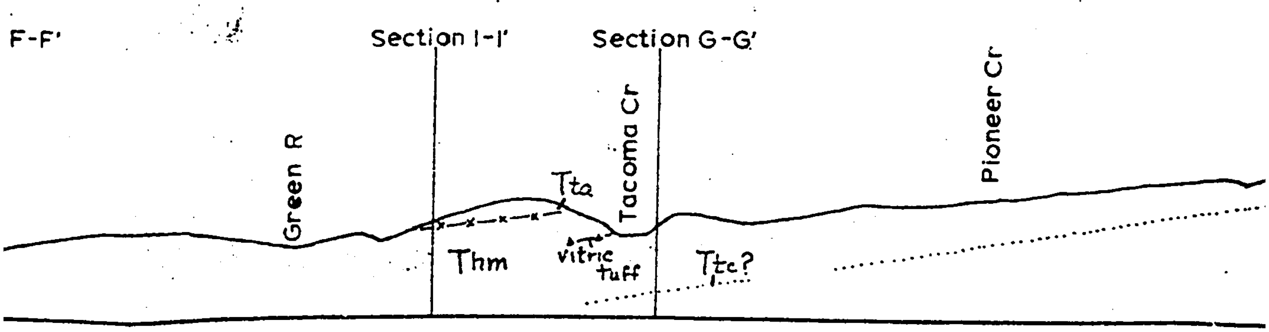
SHINGTON


Tst
Mo
Qu
Tst
Qu
Yakim
Qu
Tsc
Tn
Tn ?
Tk
Dike Complex
4000'
2000'
SL


G'
Cole Butte
syncline
Cabin Mtn
Yakima R
Qu
Tn
2000'
SL

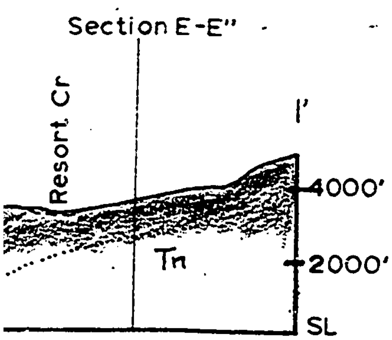

Goat Pk
H'
4000'
2000'
SL

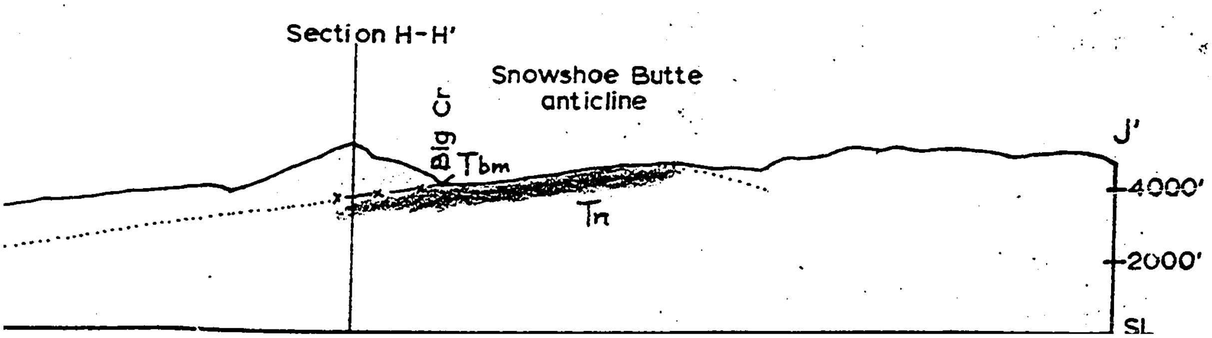

F-F'
Section E-E"
Dandy
Pass
fault
Meadow Cr
Roaring
Ridge
fault
Lk Keechelus
L Keechelus
syncline
Resort Cr
Tsc
Tsc
Tsd
Tst (prj)
Qu
Tn
Tn


F-F'
Section I-I'
Section G-G'
Green R
Tacoma Cr
Pioneer Cr
Tta
Thm
vitric
tuff
Ttc?

Q'

O'


Section E-E"
Resort Cr
I'
4000'
Tn
2000'
SL


Section H-H'
Big Cr
Snowshoe Butte
anticline
Tbm
J'
4000'
Tn
2000'
SL