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1976

Geology of the South and East Slopes
of Mount Adams Volcano,
Cascade Range, Washington

by

Kenneth Donald Hopkins

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

Doctor of Philosophy

University of Washington

1976

Approved by Steven C. Porter
(Chairperson of Supervisory Committee)

Program Authorized
to Offer Degree GEOLOGICAL SCIENCES

Date MARCH 15, 1976

UNIVERSITY OF WASHINGTON

Date: May 29, 1975

We have carefully read the dissertation entitled Geology of the South and East Slopes of Mount Adams Volcano, Cascade Range, Washington

Kenneth Donald Hopkins submitted by
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 dissertation.

Increased public and scientific interest in the Cascade volcanoes, both because of their recreational opportunities and the potential hazards they present to human population in their vicinity, has led to renewed investigation of Quaternary volcanic peaks in the Pacific Northwest. Hopkins' geologic investigation of the south and east slopes of Mt. Adams is the first detailed study of this major Cascade volcano and should constitute a basic reference work for years to come. He has made a thorough study, over approximately half the mountain, of the stratigraphy of the volcanic rocks and associated surficial sediments. Relative-age assessment, together with limited radiometric dating of both volcanic and surficial stratigraphic units, provides a chronologic framework for reconstructing the late Quaternary history of the volcano and of glaciers on its flanks. Interstratification of volcanic and glacial units on the mountain indicates that intermittent volcanic activity has occurred throughout the late Quaternary and that the latest eruption of lava postdates the Mazama tephra (6600 years old). Although Mt. Adams usually is regarded as an inactive volcano, because at least one late Holocene eruption has been documented, the eruptive history of the mountain may not yet be ended.

The glacial record preserved on the volcano bears a strong similarity to glacial successions studied elsewhere in the Washington and Oregon Cascades. Hopkins' mapping of glacial limits around Mt. Adams constitutes an important addition to knowledge of the former ice cover in the southern Cascades, and his careful dating of the Holocene moraines of Klickitat Glacier provides the best chronologic control presently available on glacier fluctuations in the extreme southern part of the state.

DISSERTATION READING COMMITTEE:

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Doctoral Dissertation

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Frontispiece. East face of Mount Adams viewed from Avalanche Valley.

INTRODUCTION

Mount Adams, in south-central Washington, is one of the large Quaternary volcanoes that dominate the Cascade Range (Fig. 1). The geology of Mount Adams has received little attention, owing primarily to difficult access, and until recently, to a lack of adequate topographic maps. The present study, which was conducted on the south and east flanks of the volcano, was undertaken to (1) identify the principal volcanic units and determine their sequence of eruption, (2) delineate a succession of Quaternary glaciations that could be compared with other Northwest chronologies, and (3) establish the relationship of glacial events to late-Quaternary volcanism. It was hoped that such a study, in addition to outlining the geologic history of Mount Adams, also would aid in establishing regional patterns of volcanism and glaciation for this little-known part of the Cascade Range.

Geographic Setting

Topography

Mount Adams volcano (3744 m) stands 2000 to 2500 m above the surrounding peaks of the Cascade Range, and forms a prominent landmark in south-central Washington. The volcano is mantled by 10 principal glaciers, ranging in length from 1.5 to 3.5 km. Most of these occupy steep, shallow troughs

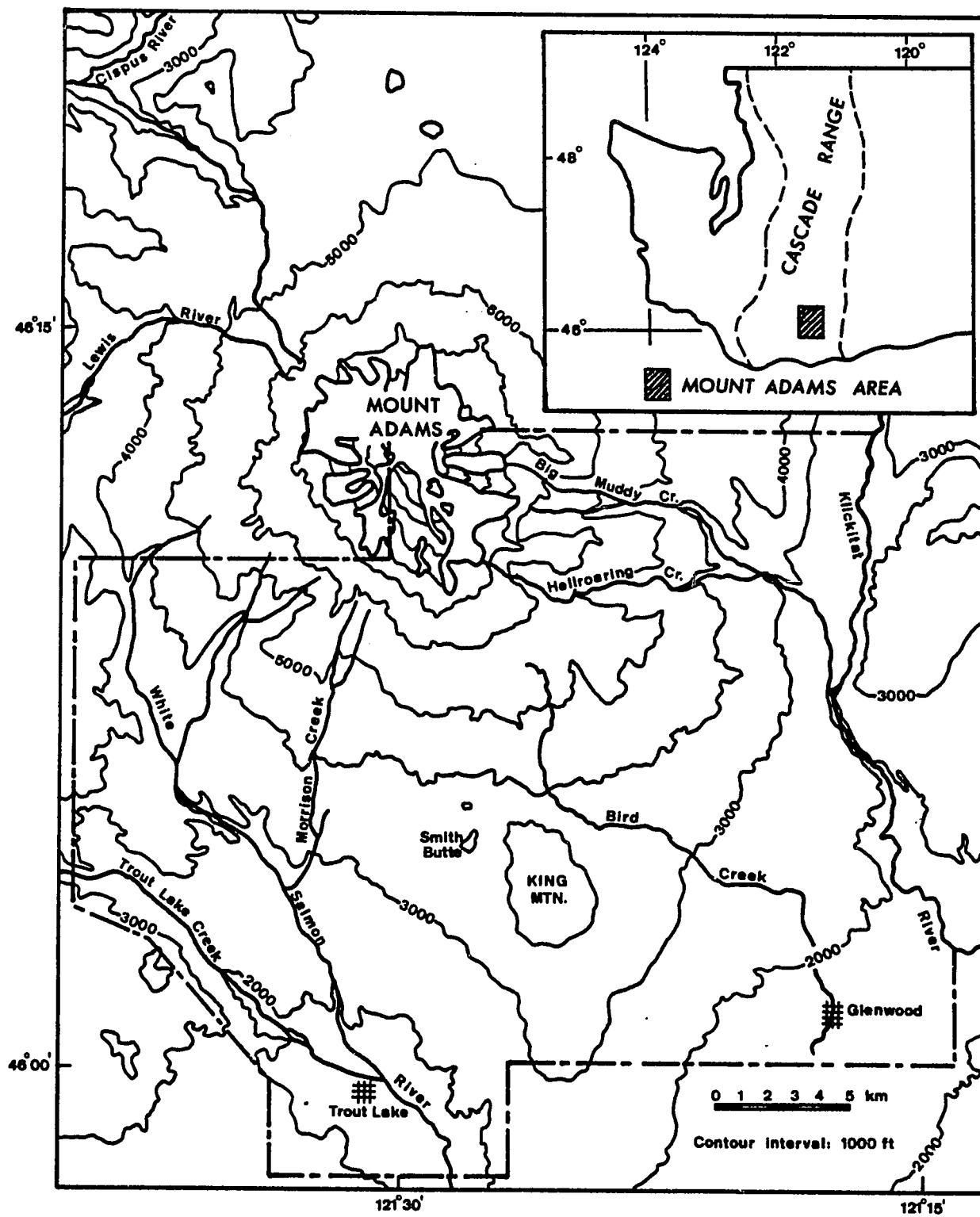


Figure 1. Index map of the Mount Adams region and its location in south-central Washington. Dash-dot line indicates boundary of area mapped.

on the flanks of the cone; however, Klickitat and Rusk glaciers lie in large, east-facing cirques with precipitous headwalls 450 to 600 m high. Slopes on the flanks of the main cone commonly are between 25 and 30 degrees, but steepen to as much as 50 degrees on the cirque headwalls above Klickitat and Rusk glaciers. Lava flows that extend beyond the base of the main cone form a broad, gently sloping apron, 5 to 9 km wide, that surrounds the volcano.

The terrain surrounding Mount Adams is part of an older landscape developed on rocks of pre-Mount Adams age. South and east of the volcano, where this surface is developed on olivine-basalt flows of early to middle Quaternary age, slopes are gentle and the relief is moderate. A conspicuous landform in this region is King Mountain, a broad shield volcano 17 km southeast of Mount Adams, whose little-dissected cone rises to an altitude of 1440 m. West and northwest of Mount Adams, where rocks of early to middle Tertiary age are exposed, the older surface is characterized by steep slopes and high relief.

The major streams draining the region are the Cispus, Lewis, and White Salmon rivers west of Mount Adams, and the Klickitat River east of the volcano. All of them lie in prominent valleys, 300 to 750 m deep. Tributaries to these rivers that head on Mount Adams form a radial pattern. Most of the radial streams occupy relatively shallow valleys (generally less than 90 m deep) where they cross the lower

slopes of the volcano. The principal exceptions are Big Muddy and Hellroaring creeks on the east flank of Mount Adams, and Cascades Creek on the southwest slope, whose steep-sided valleys are 240 to 360 m deep.

Climate

The Mount Adams area, with a maximum relief of about 3200 m, embraces a wide range of climatic conditions. However, detailed climatologic data for the area are lacking; the nearest weather station is at Trout Lake (altitude= 585 m), 23 km south of Mount Adams. Temperature and precipitation data presented here are taken from E.L. Phillips (1965), and include figures interpolated from U.S. Weather Bureau climatologic maps for Washington.

The climate of the Mount Adams area, as elsewhere on the east slope of the Cascade Range, is characterized by a rapid eastward decrease in mean annual precipitation. Estimated values range from 250 cm on the west flank of Mount Adams to 100 cm at Glenwood, 25 km southeast of the volcano. Most of the precipitation occurs during the winter months, primarily as snow. Monthly precipitation at Trout Lake, for example, normally is between 10 and 25 cm during July and August. Above 1000 m (3300 ft) snow can be expected in October. On forested slopes near timberline, snow may accumulate to depths of 3 to 5 m by early spring, and large snowbanks persist until late

June or early July. Maximum daily temperatures range widely with altitude. On the lower slopes of the volcano, the average maximum temperature for July ranges from 21° to 27°C; daily maximum temperatures for January generally are between -2° and +2°C.

Field Work

A brief reconnaissance of the Mount Adams region was made in the summer of 1966 during which promising areas for study were located, and a plan for the fieldwork was prepared. Most of the fieldwork was conducted during the months of June through September of 1967 and 1968; however, an additional week was spent in the field in 1969.

Most of the mapping was done using reconnaissance techniques. Use of these methods was necessitated by difficult access, dense forest cover, and limited exposures in many parts of the region, as well as by size of the area under study. Because adequate topographic maps were not available until after the field work was completed, mapping was done on aerial photographs. Photos having a scale of 1:20,000 were used to map bedrock and drift on the lower slopes of the volcano; large-scale photos at a scale of 1:12,000 were used to map Neoglacial moraines and dikes on the east side of the main cone. The information was transferred later to a topographic base at a scale of 1:62,500, compiled from enlargements of U.S. Geological Survey 30-minute maps. All of the altitudes used in

this report, however, are taken from the new U.S. Geological Survey 7 1/2-minute quadrangles.

Summary of Stratigraphic Units

Although volcanic rocks and surficial deposits are described in separate sections of this report, their stratigraphic relationships are a primary basis for interpreting the late-Quaternary history of the Mount Adams area. The principal stratigraphic units to be discussed are shown diagrammatically in Figure 2, and are introduced here in order to emphasize stratigraphic relationships important to the discussions that follow. The diagram shows only relative ages; vertical dimensions are not to scale.

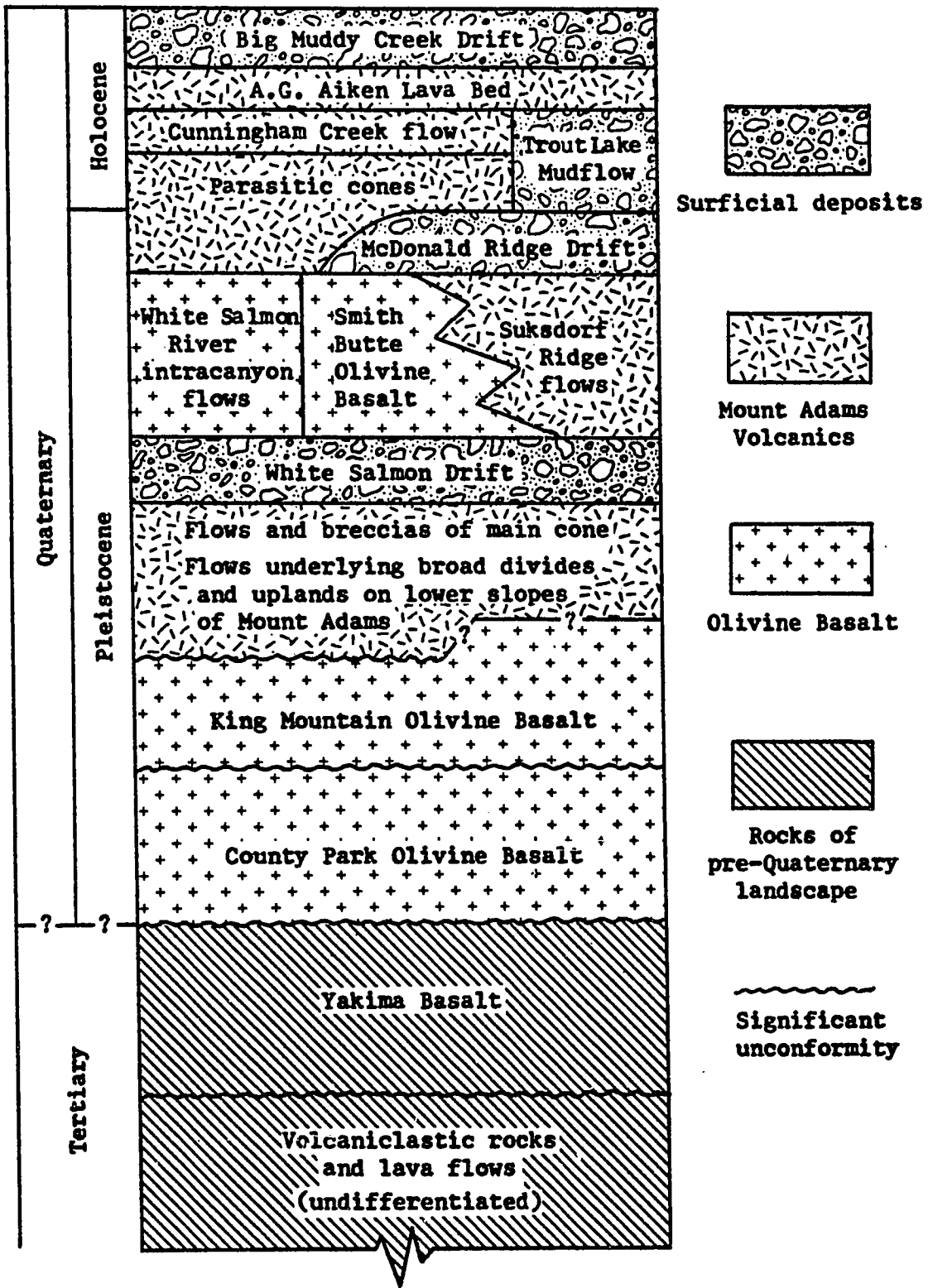


Figure 2. Relative ages of principal stratigraphic units on the south and east slopes of Mount Adams.

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Permission to conduct field studies on the Yakima Indian Reservation was granted by the Yakima Indian Tribal Council and is gratefully acknowledged. Thanks also go to the personnel of the Mount Adams District Ranger Station of the U.S. Forest Service in Trout Lake, Washington, for helpful suggestions concerning logistics, and for use of their aerial photographs. Especially appreciated are the many kindnesses and generous hospitality extended by Leonard and Juanita Rolph of Glenwood, Washington.

I am especially indebted to my wife, Audrey C. Hopkins, for sharing the rigors of fieldwork, for help in preparing early drafts of the manuscript, and for encouragement throughout the course of the study.

PREVIOUS STUDIES

Prior to this investigation, the geology of Mount Adams had received only cursory attention. Brief descriptions of the geology and physiography of the Mount Adams area have been given by Williams (1912), Rusk (1924), Fowler (1936), Throssell (1940), and Laurence (1955). Fumarolic activity on the volcano has been discussed by K.N. Phillips (1941). Early observations regarding the size and behavior of glaciers on Mount Adams were reported by Reid (1900, 1902, 1903, 1906) and Rusk (1924).

More recently, geologic mapping has been conducted in adjacent areas east of Mount Adams (Sheppard, 1960, 1967a) and south of Mount Adams (Sheppard, 1964). Petrologic and chemical data for a single Mount Adams flow were reported by Sheppard (1967b). Hammond (1973) discussed the relationship of basalt eruptive centers in the Mount Adams area to regional patterns of Quaternary basaltic volcanism.

STRATIGRAPHY AND DESCRIPTION OF ROCK UNITS

The rocks of the Mount Adams area are grouped here into two major sequences separated by a marked unconformity of late Tertiary age. The older sequence consists of deformed lava flows and volcanoclastic rocks of early to middle Tertiary age. These rocks form a terrain of moderately high relief upon which the younger sequence of very late Tertiary and Quaternary flows was erupted. The Quaternary rocks, which are of principal concern in this report, are essentially undeformed and include pyroxene andesite lavas from Mount Adams, as well as widespread olivine basalt flows from numerous peripheral vents.

Rock Nomenclature

The rock names and textural terms used here for volcanic flow rocks follow the usage of Williams (Williams and others, 1954), the classification of lavas being based on mineralogical composition. Basalt is distinguished from andesite primarily on the basis of modal color index. Where possible, the average plagioclase composition was used as a supplementary guide. However, because of the difficulty in determining the average plagioclase composition of delicately zoned grains or of strongly porphyritic lavas having small groundmass microlites, the latter criterion had limited value. In general, rocks classified as basalt have modal color indices greater than 40 percent and an average plagioclase composition more calcic than An₅₀.

The nomenclature for volcanoclastic rocks of pyroclastic origin, regardless of their mode of deposition (Fig. 3), is adapted from classifications by Wentworth and Williams (1932), Peck and others (1964), and Fischer (1960, 1966). The grain-size classification for pyroclastic rocks proposed by Fischer (1960) is followed in order to conform more nearly to standard nomenclature used for fragmental sedimentary rocks. Indurated aggregates of ash, lapilli, and blocks or bombs form the end members in this system and are called respectively, tuff, lapillistone, and pyroclastic breccia. Poorly sorted rocks containing less than 75 percent of a single end member are given mixture names based on the two principal constituents.

Volcanoclastic rocks composed of fragments of unknown origin are described using Gilbert's classification for sedimentary rocks (Williams and others, 1954, p. 289-297). The terms are used in a nongenetic sense, and are intended simply to describe textural characteristics.

Tertiary Rocks

Rocks of Tertiary age are exposed near the margins of the map area where they extend beyond the perimeter of the younger lavas from Mount Adams and adjacent shield volcanoes. The Tertiary rocks of the older sequence are divided into two principal stratigraphic units: (1) an undifferentiated succession of volcanoclastic rocks and lava flows, and (2) the Yakima Basalt.

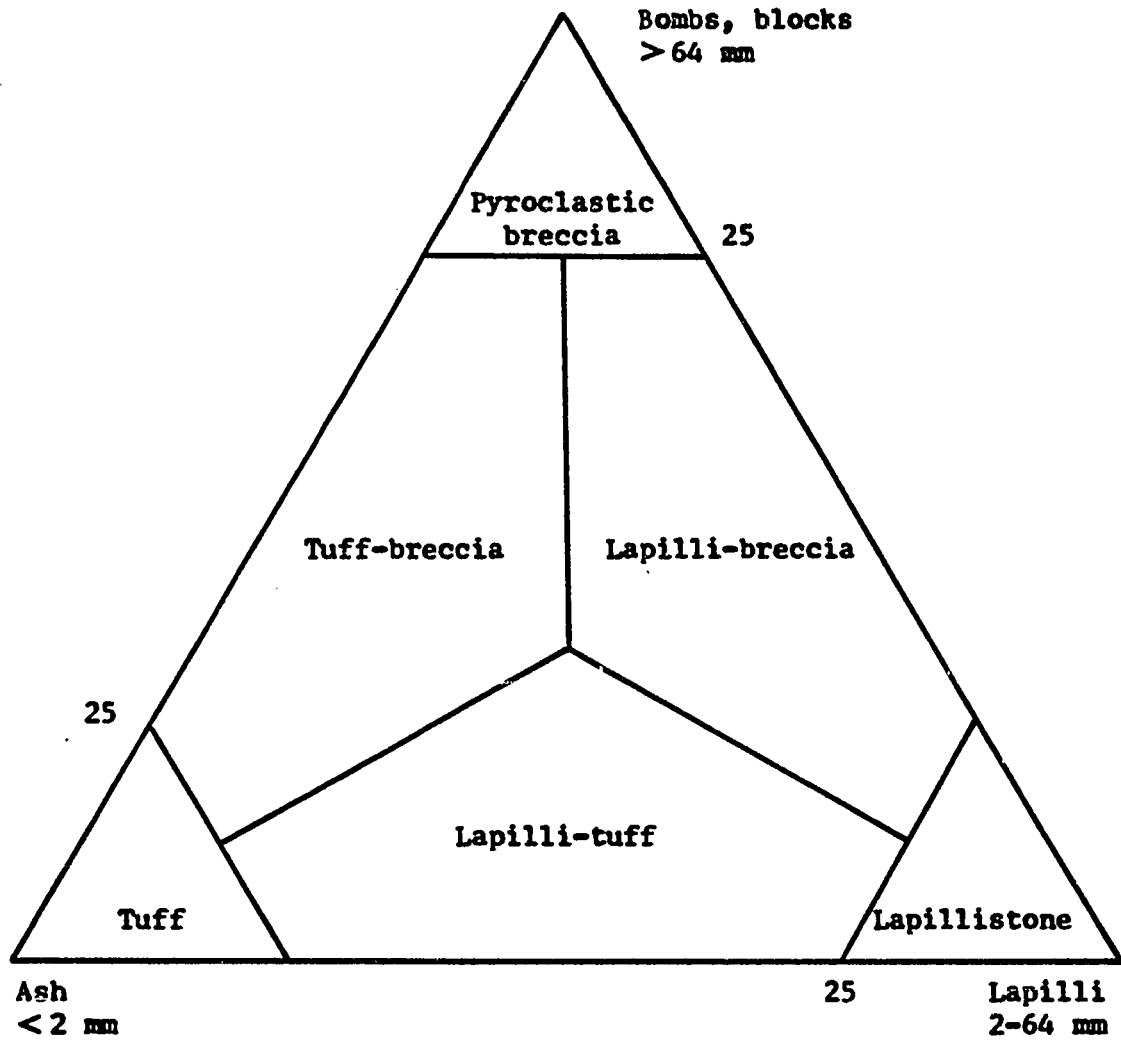


Figure 3. End-member names and mixture names used for pyroclastic rocks.

Undifferentiated volcanoclastic rocks and lava flows

The oldest rocks of the study area form a thick succession of altered and deformed volcanoclastic rocks and interbedded lava flows. Volcanoclastic rocks comprise the bulk of this unit, but a few flows occur locally. Outcrops of these rocks are restricted to the extreme western portion of the study area beyond the margin of the younger volcanic sequence. Similar rocks are exposed along the northwestern and northern margins of the Mount Adams lavas, and are widespread north, west, and southwest of the study area. Probably these rocks underlie about half of the late Tertiary landscape concealed by the younger volcanic rocks of Mount Adams and nearby vents (Fig. 4).

The volcanoclastic rocks are extremely diverse in character, although all are composed entirely of volcanic fragments. Tuff-breccia is dominant and occurs in massive beds 3 to 8 m thick. Typically, it consists of angular to subrounded clasts of lava and pumice, in a matrix containing lithic grains, crystals of plagioclase and clinopyroxene, and glass shards (Fig. 5). The abundance of pumice and glass shards suggests that these rocks are of pyroclastic origin. Interstratified with the tuff-breccia are thinner beds of volcanic wacke, volcanic arenite, and volcanic siltstone. These thinner beds are similar in composition to the tuff-breccia; however, many of them have definite sedimentary features. The arenites and siltstones commonly are stratified, and sometimes show cross-stratification and small-scale channeling. Crude stratification

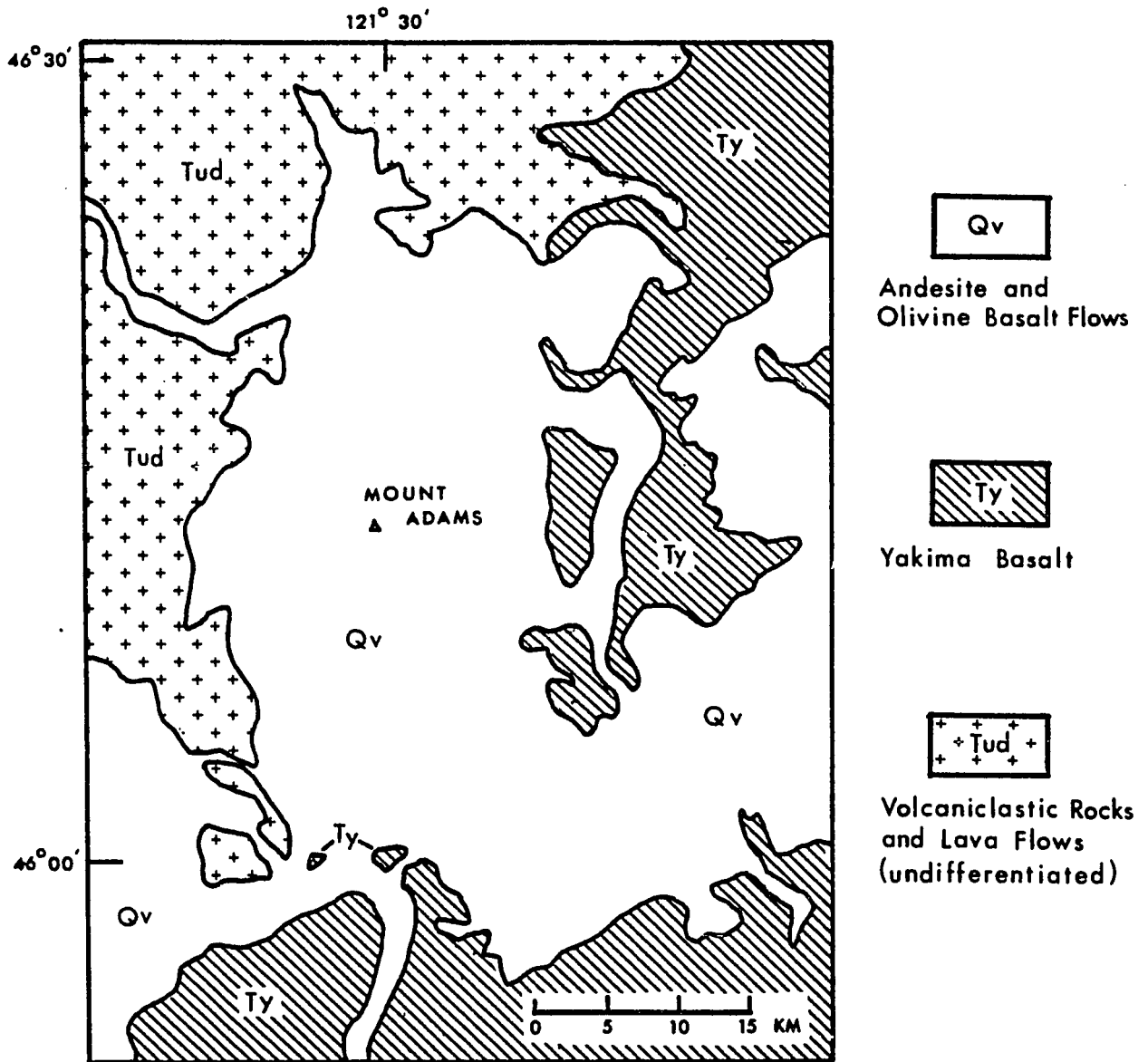
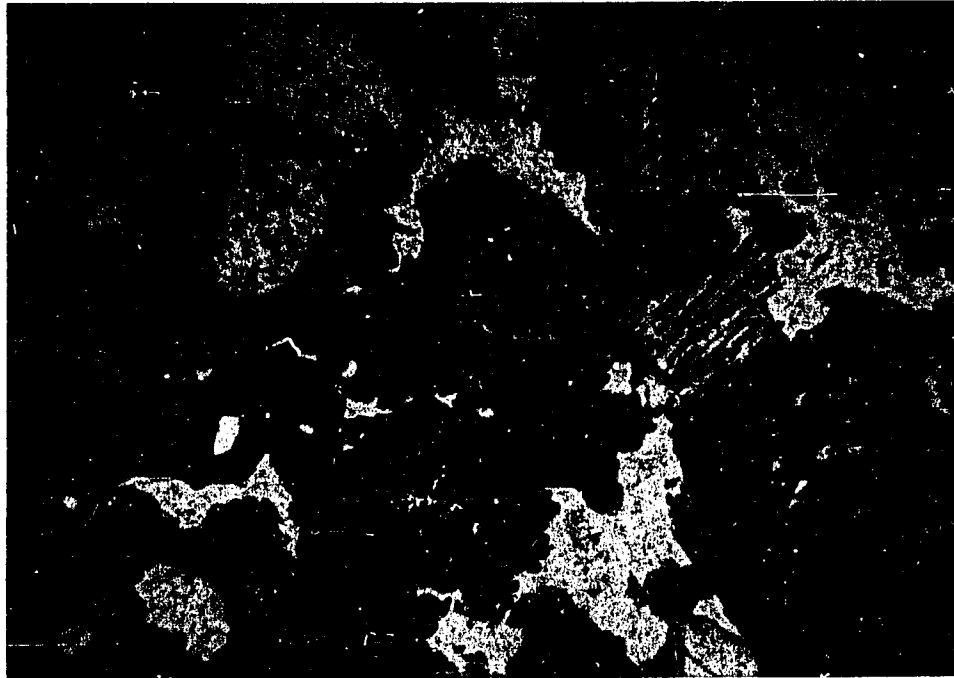


Figure 4. Distribution of Tertiary and Quaternary rocks in the Mount Adams area. Modified from the Geologic Map of Washington (Hunting, M.T., 1961).



0 0.5 mm

Figure 5. Photomicrograph of tuff-breccia. Clasts of lava and devitrified pumice in matrix of lithic grains, glass shards, and crystals of plagioclase and clinopyroxene. Plane light.

in the volcanic wackes is produced by vertical grading within thin layers, commonly 2 to 6 cm thick. All of the volcanoclastic rocks are strongly altered. The pumice clasts are largely devitrified, and finely crystalline secondary minerals cloud the groundmass. Rocks closely resembling those described above and occurring northwest and southwest of Mount Adams have been mapped as Ohanapecosh Formation (Fiske and others, 1963; Wise, 1970). Although Fiske and others (1963, p. 20) assigned a late Eocene age to the Ohanapecosh Formation on the basis of plant fossils collected near Mount Rainier, they believed that Ohanapecosh rocks may range in age from middle Eocene to early Oligocene. A small assemblage of fossils, collected from the Ohanapecosh Formation southwest of Mount Adams, is entirely of Oligocene age (Wise, 1970, p. 8).

Yakima Basalt

The Yakima Basalt (Waters, 1961) probably underlies most of the southeast half of Mount Adams and nearly all of the Quaternary olivine basalts south of the volcano (Fig. 4). The principal areas of exposure occur along the Klickitat River canyon, in the uplands immediately west of the canyon, and as isolated topographic highs that escaped burial by the Quaternary lavas in southeastern and southern parts of the area.

Near Mount Adams the Yakima Basalt typically is dark gray to black, dense, and fine grained. Weathering produces a distinctive yellowish-brown to grayish-brown coating on

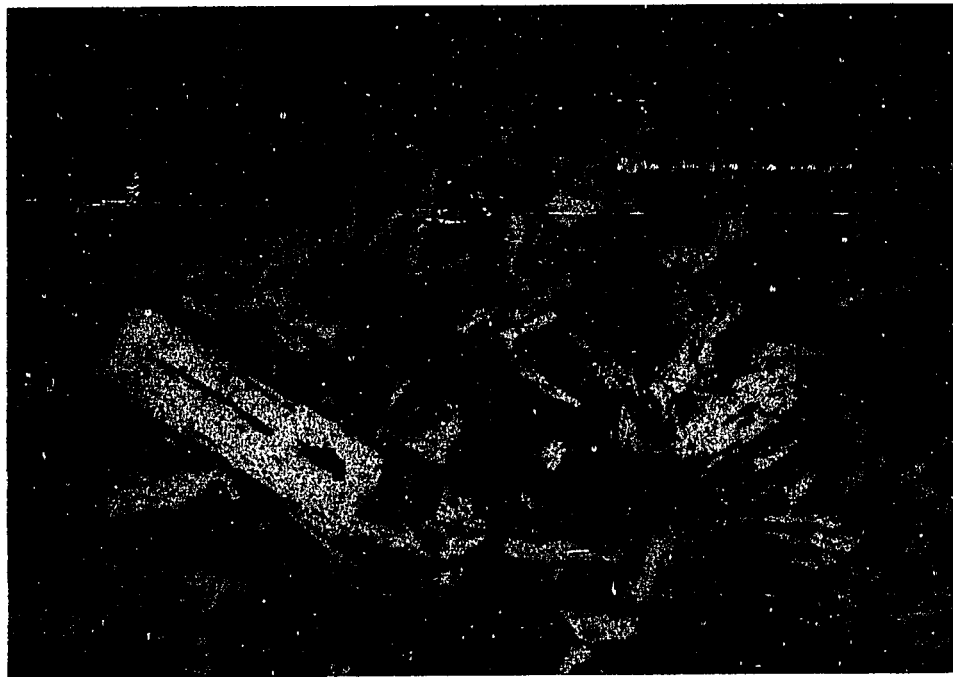
joint surfaces. The basalt is best exposed along the Klickitat River where individual flows range in thickness from 18 to 42 m. Columnar jointing is well developed, particularly in the lower portions of these flows. However, west of the canyon where exposures in the basalt are shallow, hackly to poorly developed blocky jointing is dominant (Fig. 6).

In thin section the Yakima Basalt is nonporphyritic, although in some flows a few scattered microphenocrysts of plagioclase occur (Fig. 7). The basalt consists mainly of plagioclase laths (average composition= An_{50}) and pale gray clinopyroxene ($+2V=36-44^\circ$) in an intergranular relationship. Olivine is rare or absent in most sections; probably it averages less than 1 percent of the rock. All flows are to some degree intersertal, owing to the presence of interstitial glass which comprises 8 to 20 percent of the rock. Some flows contain an interstitial, yellowish-green mineraloid, usually less than 8 percent, which has been identified by some workers as chlorophaeite (e.g. Peacock and Fuller, 1928; Waters, 1961). Opaques are a common accessory and comprise about 5 percent of the rock.

The base of the Yakima Basalt is not exposed in the map area. Outcrops of Yakima Basalt and the older volcanoclastic rocks are separated by 600 m on opposite sides of a small valley in NE 1/4, sec. 16, T.6N, R.10E. However, probably these two units are in fault contact beneath the valley floor, the actual contact being concealed by younger, valley-filling



Figure 6. Yakima Basalt showing poorly developed blocky jointing.



0 0.5 mm

Figure 7. Photomicrograph of Yakima Basalt showing fine-grained intergranular texture of plagioclase and clinopyroxene. Plane light.

basalt flows and alluvium.

The total thickness of the Yakima Basalt exposed in the map area is difficult to estimate owing to the generally poor exposures; however, Sheppard (1960, p. 14) reports an exposed thickness of almost 435 m on the east wall of the Klickitat River canyon near the northeast corner of the map area.

According to Waters (1961), eruptions of the Yakima Basalt began in the middle or late Miocene and continued into the early Pliocene. His estimate is based on stratigraphic relationships of the basalt to adjacent fossil-bearing sedimentary strata, and on diatoms and molluscs which occur in lacustrine interbeds.

Quaternary Olivine Basalt Flows

Olivine basalt flows cover about 280 km² of the map area. The bulk of these flows are of Quaternary age, but the earliest eruptions of olivine basalt may have occurred in late Pliocene time. Olivine basalt flows that were extruded mostly from vents near Mount Adams are grouped into three map units: (1) County Park Olivine Basalt, (2) King Mountain Olivine Basalt, and (3) Smith Butte Olivine Basalt. Two additional units include intracanyon olivine basalt flows of the White Salmon and Klickitat valleys which were extruded from vents outside the area. This subdivision is based primarily on relative age, source area, and lithology of flows, although not always with

equal emphasis.

Owing to a lack of good vertical exposures in the olivine basalts, the evidence for the sequence of extrusion is based heavily on geomorphic criteria. Typically, superposition of flows can be seen only along flow margins. However, many flows have abrupt, well-defined edges, traceable on aerial photographs, whereby a succession of overlapping flows can be delineated. Other useful geomorphic criteria of relative age are the extent to which the original flow-surface morphology has been modified, the relationship of flows to episodes of valley cutting, and the presence or absence of prominent vents. In some of the older flows olivine phenocrysts have weathered to a reddish-brown alteration product. However, because some of this alteration may be deuteric, and therefore unrelated to age, this criterion must be applied with appropriate caution.

Many of the olivine basalt flows cannot be traced to a specific vent, but most can be related to several broadly defined centers. The olivine basalts are virtually undeformed and therefore still retain their original dips away from eruptive centers. By tracing flow margins, individual flows within a volcanic unit can sometimes be delineated and related to a vent or group of vents. Stretched vesicles are common in the tops of many flows, but pipe vesicles are too rarely seen to be useful as flow-direction indicators.

The principal groups of flows, although mineralogically

similar, are sufficiently different to be distinguished in thin section. In the field, they often can be distinguished on the basis of macroscopic features such as color and texture, as well as size, frequency, and nature of phenocrysts.

County Park Olivine Basalt

Definition, distribution, and source. The County Park Olivine Basalt includes all preglacial olivine basalt flows in the study area except those of King Mountain volcano. Although the County Park flows were erupted from several source areas, they have many similarities and are grouped together here for convenience of description. The name refers to a small county park in the NE 1/4, Sec. 11, T.6N, R.11E. where the basalt is well exposed in a roadcut (Fig. 8). The basalt at this locality, however, is not representative of the entire unit.

The most extensive series of flows covers an area of about 40 km² on both sides of the White Salmon River at the south base of Mount Adams. The flows underlying the ridge west of the river dip gently (0-5°) southeast, probably at their initial angle. Two poorly exposed, rounded hills on the crest of this ridge may be eroded remnants of vents from which some of these flows were extruded. However, most of the flows which form the ridge probably came from vents farther north which are now covered by younger lavas, or from vents west of the map area. The flows east of the river have slight south to southeast dips, and apparently were extruded sometime later from a different source. None of the vents for these flows

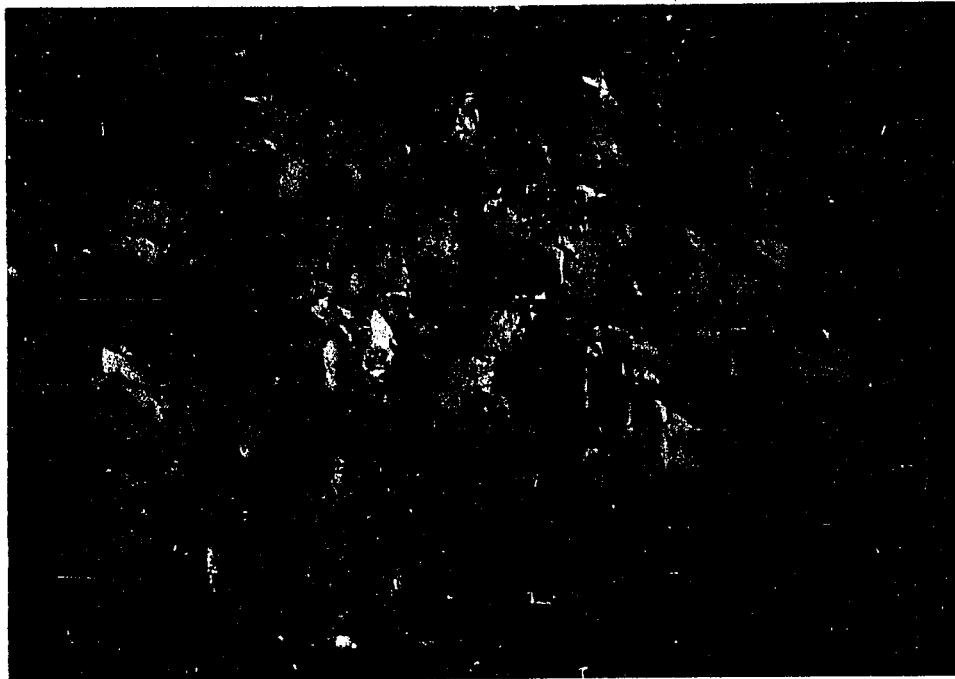


Figure 8. County Park Olivine Basalt showing poorly developed blocky jointing.

are evident; presumably they are buried beneath the younger andesite flows of Mount Adams to the north.

Two smaller areas of outcrop are located southeast of the volcano between Bird Creek and Dairy Creek. No vents for these flows were found in the map area. In thin section, however, this basalt closely resembles the Simcoe Olivine Basalt (Sheppard, 1960, 1967a) which is widespread east of the Klickitat River canyon.

Field description. The County Park Olivine Basalt usually can be distinguished from the underlying Yakima Basalt by its lighter color, fresher appearance, coarser texture, and sometimes by its conspicuous olivine phenocrysts. Most flows are medium gray, but they range from light to dark gray. Phenocrysts of olivine up to 3 mm in diameter are moderately abundant except in the flows immediately east of the White Salmon River, which are exposed at the County Park locality. These flows, although not conspicuously porphyritic, contain scattered, small phenocrysts of plagioclase and subordinate olivine.

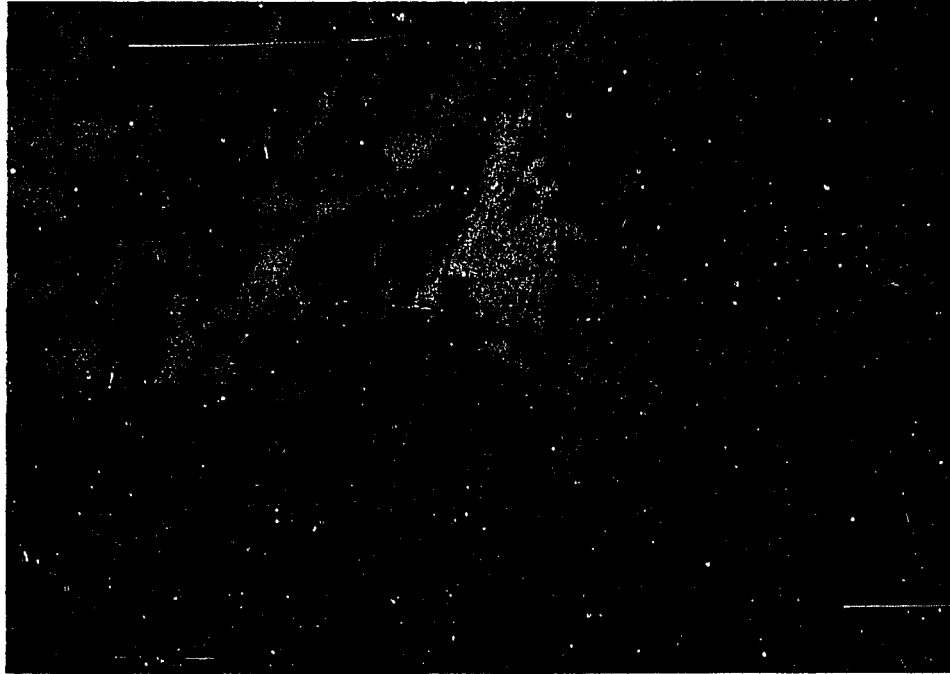
Individual flows of the County Park Olivine Basalt typically are 3 to 6 m thick and massive; however, platy jointing and crude blocky jointing are sometimes seen (Fig. 8). The tops and bottoms of many flows are moderately vesicular, and in some cases, brecciated.

Erosional modification of the County Park flows is most evident on the ridge separating Trout Lake Creek and the White Salmon River. None of the original flow-surface morphology

remains, and the rolling surface suggests that the uppermost flows may have been largely removed. Valleys have been cut along both sides of the ridge to depths of 90 to 120 m or more below the surface. The flows east of the White Salmon River, although not so greatly eroded, have been notched by numerous small channels, and little of the original surface remains.

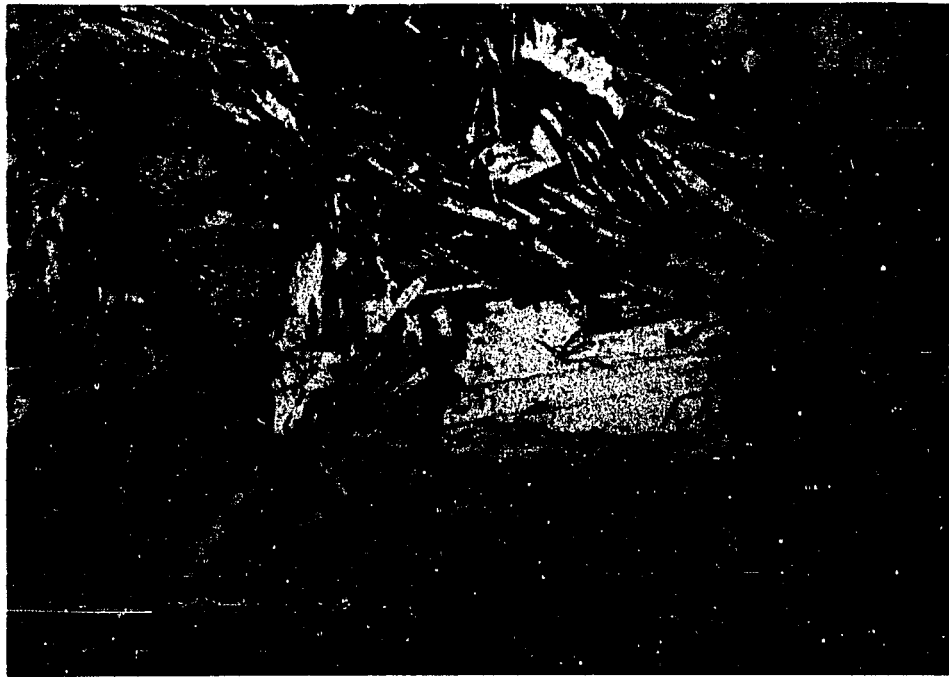
Petrography. All of the County Park Olivine Basalt flows are holocrystalline (or nearly so) and porphyritic. Two principal kinds of flows can be distinguished, however, on the basis of textural characteristics. About half the flows, including those at the County Park locality, have a subophitic groundmass of randomly oriented plagioclase laths and ferromagnesian minerals, and are diktytaxitic (Fig. 9). Most other flows, particularly those west of the White Salmon River, have an intergranular groundmass showing moderate flow alignment of plagioclase microlites, and are not diktytaxitic (Fig. 10). Combinations of textures other than these are rare; most flows can be placed in one or the other of the above categories.

In the intergranular olivine basalts, phenocrysts usually show a crude parallelism with the flow-aligned groundmass microlites. In the vicinity of phenocrysts, the flow alignment often is disrupted and the microlites more nearly parallel the outline of larger grains. Platy jointing, although uncommon, is most often seen in these flows and probably is favored by



0 0.5 mm

Figure 9. Photomicrograph of County Park Olivine Basalt. Olivine phenocryst in subophytic groundmass of plagioclase laths and ferromagnesian minerals. Plane light.



0 0.5 mm

Figure 10. Photomicrograph of County Park Olivine Basalt showing moderate flow alignment of plagioclase microlites in intergranular groundmass. Plane light.

the subparallel arrangement of plagioclase laths.

Typically, phenocrysts comprise about 10 to 15 percent of the County Park Olivine Basalt. Plagioclase and olivine are the principal phenocryst minerals and either may predominate. Clinopyroxene occurs rarely as phenocrysts in some of the intergranular flows.

Phenocrysts of plagioclase generally are 0.8 to 1.5 mm long, but may reach 4 mm in length. Euhedral and subhedral forms are most common with some grains having ragged edges and spongy, inclusion-rich cores. Most plagioclase phenocrysts show weak to moderate normal zoning or are unzoned, and range in composition from An₅₅ to An₇₀.

Olivine ($-2V=80-87^\circ$) forms subhedral to anhedral phenocrysts, generally from 1 to 3 mm in diameter, and sometimes occurs in small glomeroporphyritic clots with plagioclase. Nearly all grains are partly or entirely rimmed by a strongly absorbing, reddish-brown alteration product (iddingsite?), and in some grains this alteration extends inward along fractures.

Phenocrysts of clinopyroxene are sparse, occurring only in the intergranular flows and usually in glomeroporphyritic clots with olivine and plagioclase. All of these grains have a pale brown color, positive sign, and moderate optic angle ($45-55^\circ$) indicative of augite.

Plagioclase is the principle constituent of the groundmass, occurring as small laths and anhedral grains from 0.08 to 0.5 mm long. Clinopyroxene and olivine are present in

variable amounts as small anhedral grains averaging about 0.2 mm in diameter. Opaque grains, comprising about 5 to 10 percent of the rock, are scattered throughout the groundmass and sometimes occur as small inclusions in phenocrysts, particularly in olivine. Apatite, glass, and alteration products together comprise about 2 percent of the groundmass.

Age. The age of the County Park Olivine Basalt can be bracketed broadly from stratigraphic and morphologic evidence. Extrusion of the basalt was not confined to a single eruptive episode, but the unit as a whole probably is not older than late Pliocene nor younger than middle Quaternary.

Within the map area the County Park flows overlie Yakima Basalt (late Miocene to early Pliocene). However, the County Park Olivine Basalt overlies the Yakima Basalt with angular unconformity, generally shows much less weathering and erosion than does the Yakima Basalt, and clearly was extruded much later.

Similar and possibly equivalent olivine basalt flows in the Simcoe Mountains area east of the Klickitat River overlie folded and eroded Ellensburg Formation of Pliocene age (Sheppard, 1960, p. 40). Throughout most of the Simcoe Mountains area, however, the Ellensburg Formation was completely removed by erosion before the olivine basalt was extruded (Sheppard, 1960, p. 36), indicating that extrusion of the olivine basalt there may not have occurred much before late Pliocene time.

A minimum age of middle Quaternary is indicated for the County Park Olivine Basalt on the basis of its stratigraphic position beneath late Quaternary glacial drift (White Salmon till). Beyond the drift limit, in the southeastern part of the area, the County Park Olivine Basalt is overlapped by lava flows from King Mountain shield volcano. These flows are thought to predate the drift, but proof is lacking.

King Mountain Olivine Basalt

Definition, distribution, and source. The King Mountain Olivine Basalt consists of numerous, widespread flows which were extruded from a prominent shield volcano 17 km south-southeast of Mount Adams. Most flows spread radially from a central vent. The most extensive flows spread east and southeast beyond the map boundaries where they flooded the valley of Camas Prairie (Sheppard, 1964) and entered the ancestral Klickitat Canyon (Sheppard, 1960, p. 83).

The source of the flows was King Mountain (Fig. 11); a broad, smoothly sloping shield whose form is partly coalescent with the southern slope of Mount Adams. The diameter of the shield at its base ranges from 7 km (north-south) to 13 km (east-west), and, owing to irregularities of the landscape buried by the volcano, the height of the crater rim above the surrounding terrain ranges from 150 to 750 m. The summit crater is well defined and measures about 600 m across and 30 to 45 m deep. A 60 m high basaltic cinder cone, built during a late stage of activity, rests on the north rim of the crater



Figure 11. Southwest flank of King Mountain shield volcano from Trout Lake.

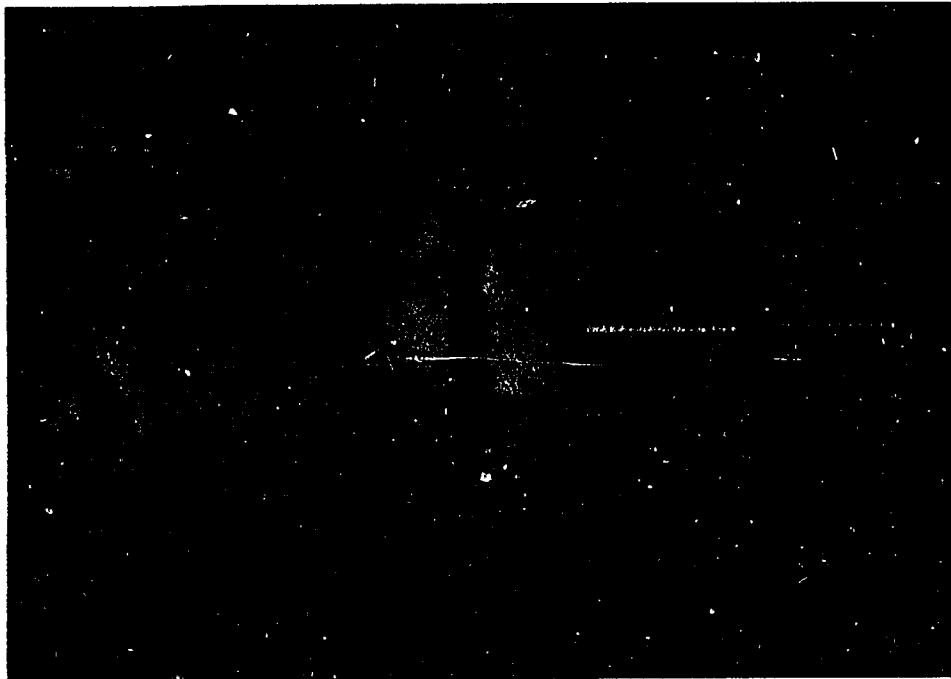


Figure 12. Outcrop of King Mountain Olivine Basalt showing crude blocky jointing and yellowish-brown oxidation on joint surfaces.

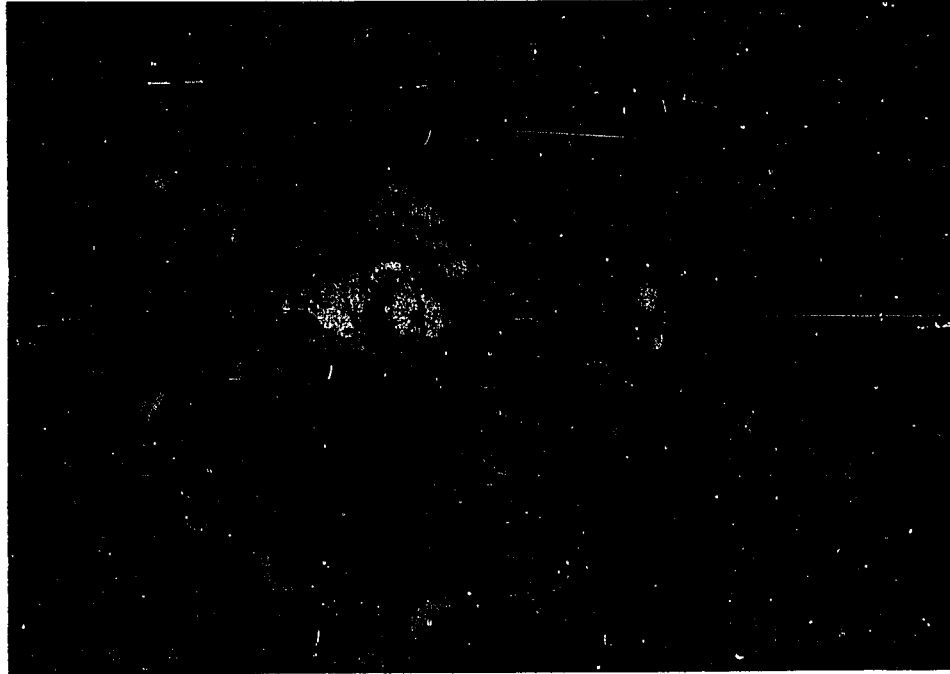
and extends over the edge to the crater floor.

Field description. Individual flows of the King Mountain Olivine Basalt generally are between 3 and 6 m thick. Most flows are massive or have a poorly developed blocky jointing (Fig. 12); however, local brecciated zones are present. The basalt is moderately vesicular, except near the tops of flows where it may be highly vesicular and where vesicles from 1 to 3 cm in diameter are common. The rock is medium to dark gray where fresh, but weathers to a characteristic yellowish-brown.

In hand specimen, large glomeroporphyritic clots of green olivine usually are visible and are a distinctive feature of the King Mountain basalt. Plagioclase forms small phenocrysts that usually appear as numerous white flecks, especially where the rock is slightly weathered.

Petrography. The King Mountain Olivine Basalt is holocrystalline, diktytaxitic (sometimes macroscopically so), and porphyritic. The phenocrysts, which comprise 10 to 15 percent of the rock, are mainly plagioclase and olivine; however, clinopyroxene occurs as scattered phenocrysts in some flows. The groundmass contains randomly oriented plagioclase laths together with subophitic to ophitic clinopyroxene, olivine, and opaque minerals. Glomerocrysts are common; most are olivine (Fig. 13), but some contain plagioclase and olivine + plagioclase.

Plagioclase is the most abundant mineral in the King



0 0.5 mm

Figure 13. Photomicrograph of King Mountain Olivine Basalt showing glomerocryst of olivine in diktytaxitic groundmass. Crossed nicols.



0 0.5 mm

Figure 14. Photomicrograph of King Mountain Olivine Basalt showing olivine phenocryst with altered rim. Plane light.

Mountain Olivine Basalt, occurring in both the phenocryst and groundmass portions. Most phenocrysts are subhedral, 0.8 to 2.0 mm long, and are either normally zoned or unzoned. Zoned grains usually have a broad, uniformly calcic core (An_{54-58}) surrounded by a narrow, normally zoned rim (An_{50-54}). Oscillatory zoning is not common, but is present in the outer portion of some grains. The groundmass plagioclase ranges in size from 0.1 to 0.3 mm and has an average composition of An_{48} .

Olivine forms single phenocrysts of subhedral to anhedral form averaging 1 mm in diameter; glomerocrysts of olivine may reach 2 to 4 mm. All grains are optically negative and have optic angles ranging from 78° to 84° . In some flows, olivine phenocrysts are partly rimmed with the same reddish-brown alteration product (Fig. 14) seen in the County Park Olivine Basalt, although much less extensively so. Groundmass olivine occurs as small anhedral grains, generally less than 0.3 mm in size.

A pale brown clinopyroxene ($+2V=46-52^\circ$) occurs as small phenocrysts in some flows, but is most abundant as a groundmass constituent. Phenocrysts have subhedral to anhedral form and average about 0.5 mm in diameter. Clinopyroxene is the dominant dark mineral in the groundmass where it exists in a subophitic to ophitic relationship with plagioclase.

Magnetite occurs both interstitially and as small, subhedral crystals in the groundmass. It ranges widely in abundance, being as little as 3 percent in some flows and as much

as 15 percent in others.

Age. The age of the King Mountain Olivine Basalt cannot be closely established from field evidence. However, stratigraphic relationships of the King Mountain flows to adjacent rock units suggest an approximate middle Quaternary age.

Flows from King Mountain overlap the County Park Olivine Basalt of probable early Quaternary age. Generally, they show much less erosional modification than do the County Park flows, and may be considerably younger.

Possible additional evidence for an erosional interval between eruption of the County Park Olivine Basalt and the King Mountain Olivine Basalt is provided by stratigraphic relationships between these two units in the Klickitat Canyon. Lava which flowed down the southeast flank of King Mountain flooded the broad valley at its base near Glenwood and spilled into the Klickitat Canyon to the east. Prior to extrusion of King Mountain lava, the ancestral Klickitat Canyon had been cut through an older sequence of olivine basalt flows into underlying Yakima Basalt (Sheppard, 1960, p. 83). The older sequence of flows is the Simcoe Olivine Basalt of Sheppard (1960) which appears to be equivalent to the County Park Olivine Basalt in the eastern part of the study area. If so, a significant period of canyon cutting must have separated extrusion of County Park Olivine Basalt and the King Mountain flows.

King Mountain Olivine Basalt antedates Mount Adams

andesite wherever the two units have been found in contact. King Mountain flows which filled the ancestral Klickitat Canyon subsequently were incised by the Klickitat River to form another gorge more than 120 m deep. Following this second episode of canyon cutting, the gorge was filled by a single, large andesite flow from Mount Adams. At two localities, on the south and southeast sides of Mount Adams, King Mountain Olivine Basalt is overlapped by andesite flows from Mount Adams. However, at neither locality were the andesite flows extruded during the early history of Mount Adams. Nowhere can Mount Adams flows that unequivocally are among the first erupted be found in contact with King Mountain Olivine Basalt. Therefore, although King Mountain appears to antedate the bulk of the main cone of Mount Adams, it is not known if extrusion of King Mountain lava ceased before the earliest eruptions of Mount Adams.

Extrusion of King Mountain Olivine Basalt is thought to have preceded deposition of the White Salmon Drift, although nowhere does White Salmon Drift rest directly on King Mountain flows. In many places on the north, west, and southwest slopes of King Mountain volcano, the olivine basalt flows are mantled by patches, up to 30 cm thick, of yellowish-brown, oxidized silt and fine sand. Similar sediment is widespread on the White Salmon Drift several miles to the west and is believed to be loess deposited immediately after recession of the glacier which deposited the White Salmon Drift.

Although major eruptions from King Mountain probably had

ceased before the late Quaternary, some minor eruptive activity continued sporadically in the vicinity of the summit crater. The cinder cone on the north rim of the crater clearly post-dates the extrusion of large flows from the crater, but the time separating the last major eruption and building of the cone is difficult to estimate.

Smith Butte Olivine Basalt

Definition, distribution and source. The Smith Butte Olivine Basalt consists of a series of thin olivine basalt flows, interbedded breccia layers, and scoria deposits which occupy an area of slightly more than 30 km² at the southern base of Mount Adams. Eruptions occurred from numerous vents within the 30 km² area. Some of the vents are marked by cinder cones, others by steep-sided mounds of blocky lava, and probably still other vents exist which are unmarked or buried by later flows. The materials extruded from these vents are referred to collectively as the Smith Butte Olivine Basalt after the largest of the included cinder cones.

Field description. The Smith Butte Olivine Basalt is dark gray to almost black, rather finely crystalline, and includes both porphyritic and nonporphyritic flows. Individual flows range in thickness from 1.5 to 4.0 m, averaging about 2.7 m. Flows are predominately massive, but may have a basal breccia and/or a brecciated top. Vesicles are few or absent in the interiors of most flows, but are abundant near the tops and bottoms, and frequently are stretched or flattened.

In many places, breccia forms about 30 percent of a flow unit, but this proportion varies widely from near zero to slightly more than 50 percent. Most breccias grade either upward or downward into massive lava, and sometimes include small tongues of lava (Fig. 15). Breccia fragments generally are less than 15 cm in diameter, have irregular, spinose form, and range from highly vesicular to rather dense. The breccias are monolithologic, consisting entirely of fragments having the same composition as the suprajacent or subjacent lava, and probably are flow breccias produced by autobrecciation of lava during movement of flow.

The surface of the Smith Butte Olivine Basalt shows only slight erosional modification. Pressure ridges, lava channels, flow edges, and other primary flow-surface features, although obscured by dense forest, are still recognizable. Surface drainage is characterized by a relatively low drainage density, and is composed of small streams occupying shallow channels. Drainage lines occasionally are discontinuous, indicating the presence of some subsurface flow.

Scattered throughout the area covered by Smith Butte Olivine Basalt are several small, blocky flows which represent some of the latest eruptions of this unit (Fig. 16). They form steep-sided mounds from 5 to 35 m high and from 100 to 450 m across, and are composed predominately of subangular blocks ranging from 10 to 50 cm in diameter. Most blocks are moderately stable except on steeper slopes at the flow edges.

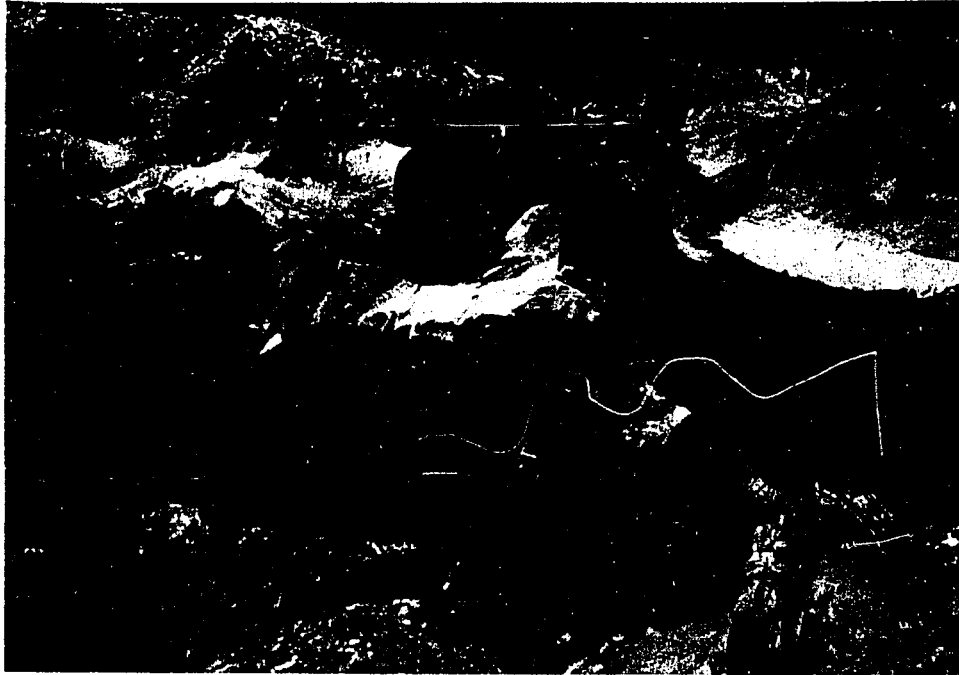


Figure 15. Smith Butte Olivine Basalt flow with central massive zone and basal breccia.



Figure 16. Blocky flow of Smith Butte Olivine Basalt in NE 1/4, Sec.2, T.6N., R.10E.

Interstices between the blocks generally are open, but locally they have been filled with finer sediments. Vegetation is sparse, but where patches of soil exist, trees as much as 50 to 70 cm in diameter are growing. Most such flows do not appear to have moved far from their sources and probably cover the vents from which they were extruded.

Cinder cones of Smith Butte Olivine Basalt form prominent, rounded hills from 35 to 120 m high and from 200 to 760 m in basal diameter (Figs. 17 and 18). Most of the 8 or 9 cinder cones visible on air photos are little eroded and have summit craters; however, minor radial gullying and mass-wasting of crater rims is evident. A few cones have breached or cleft craters, but probably these are primary features produced by laterally directed explosions. Most cinder cones are composed of stratified red, gray, and black scoriaceous basalt lapilli, together with occasional bombs and blocks, and a minor amount of ash (Figs. 19 and 20). An estimated 80 percent of the particles have diameters falling in the range of 1 to 10 cm. Bombs vary considerably in size and form, but most are crudely spindle shaped and less than 30 cm long.

Petrography. Flows of Smith Butte Olivine Basalt typically are holocrystalline, intergranular, and porphyritic. Exceptions include the tops of flows where glass fills some of the interstices in the groundmass, and some nonporphyritic flows. Many flows are diktytaxitic (Fig. 21), but the voids are not nearly so large or so numerous as in the King Mountain

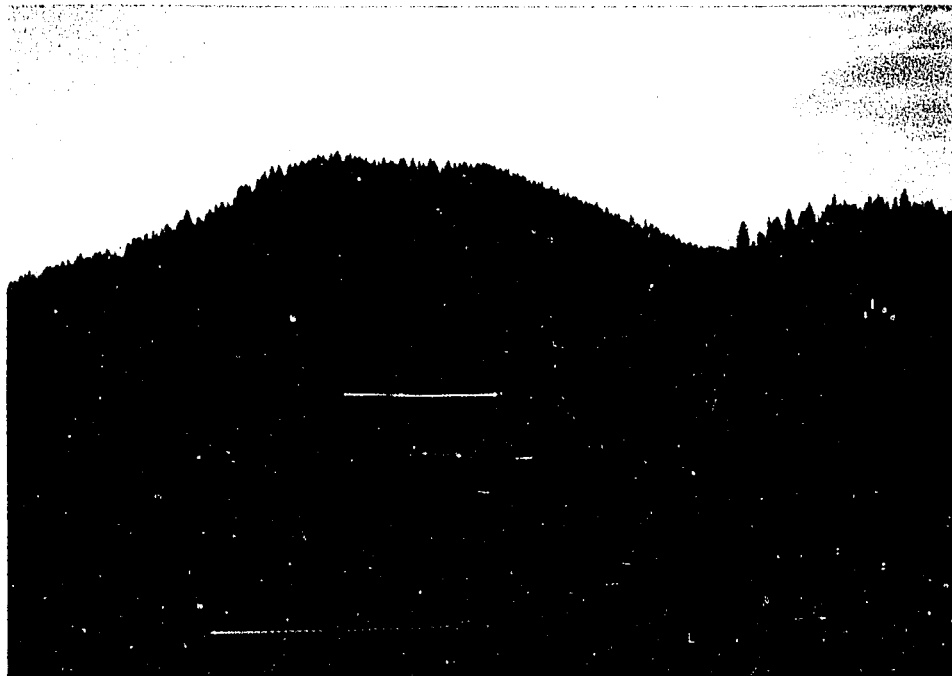


Figure 17. Smith Butte, largest of the Smith Butte Olivine Basalt cinder cones.



Figure 18. Cinder cones of Smith Butte Olivine Basalt. King Mountain in left background.

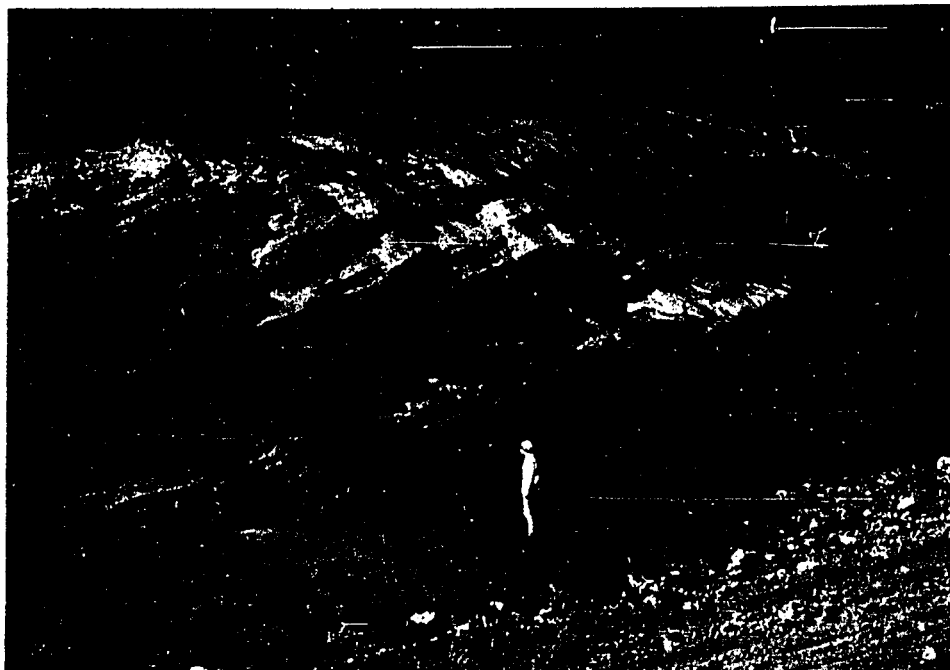
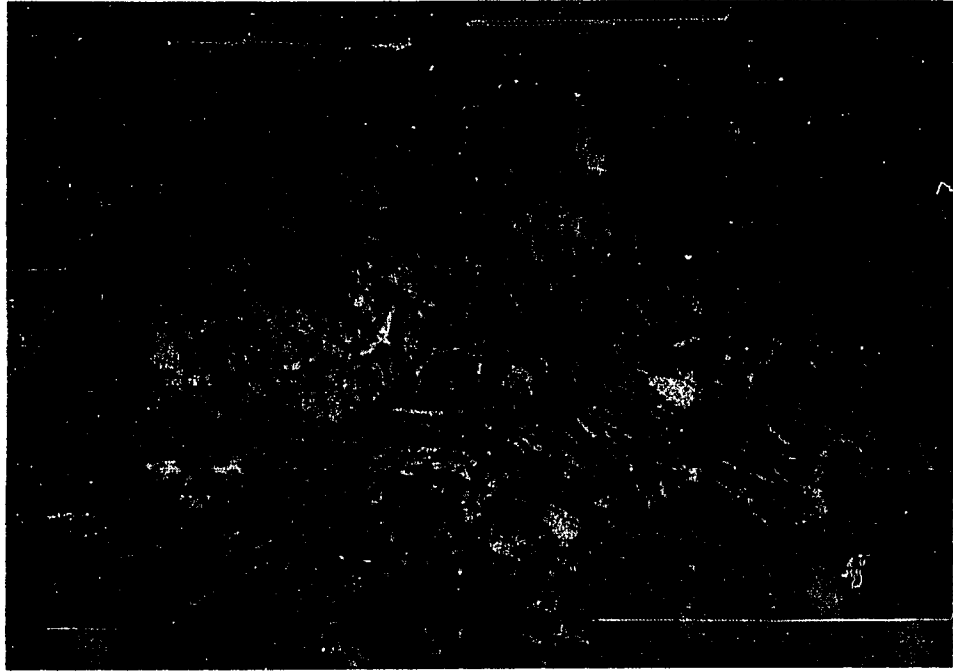


Figure 19. Stratified cinders exposed in Bunnell Butte cinder cone.



Figure 20. Cinders from Bunnell Butte cinder cone. Angular shapes predominate over streamlined forms.



0 0.5 mm

Figure 21. Photomicrograph of Smith Butte Olivine Basalt showing olivine phenocryst in intergranular groundmass. Plane light.

Olivine Basalt.

Phenocrysts comprise 10 to 15 percent of the porphyritic flows. Most are olivine, but occasional phenocrysts of plagioclase occur. Olivine phenocrysts have diameters of 0.4 to 2.0 mm, anhedral to subhedral form, and are optically negative ($-2V=84-87^\circ$). Notably absent are the reddish-brown alteration rims commonly found on olivine phenocrysts in the County Park Olivine Basalt and in some flows of King Mountain Olivine Basalt. The few plagioclase phenocrysts present have subhedral form, some with serrated edges, and are 0.4 to 2.3 mm long. The scarcity of plagioclase phenocrysts makes compositional determinations uncertain, but an average composition of An_{57} was determined from several weakly zoned grains.

The groundmass consists primarily of a network of subparallel plagioclase laths, 0.1 to 0.2 mm long, with interstitial clinopyroxene and magnetite. Glass, olivine, and other accessory minerals together account for less than 5 percent of the groundmass.

Age. A late-Quaternary age for the Smith Butte Olivine Basalt is indicated by the relative freshness of surface morphology, and by stratigraphic relationships with adjacent volcanic units. Smith Butte Olivine Basalt overlaps King Mountain Olivine Basalt of inferred middle-Quaternary age, and intertongues with relatively young flows of Mount Adams Andesite.

Moreover, stratigraphic relationships of Smith Butte

Olivine Basalt with glacial drifts suggest that most of the basalt was erupted during Olympia time (Fig. 42). The westernmost flows of Smith Butte Olivine Basalt appear to overlap till thought to be of Salmon Springs age (White Salmon Till). The basalt, in turn, is overlapped by andesite flows from Mount Adams which can be traced up the south slope of the volcano to a position beneath till of Fraser age (McDonald Ridge till).

The small, blocky flows described earlier and some of the cinder cones appear sufficiently fresh to be younger than Olympia, although their youthful form may be deceiving. The high permeability of these features reduces runoff, and in the case of the blocky flows, a complete lack of fines greatly retards soil formation and growth of vegetation. For example, a minimum age of pre-Fraser can be established for Snipes Mountain (Sec.8, T.7N., R.11E.), a relatively little-eroded cinder cone at the base of Mount Adams. The cinder cone stands in the path of a late-Quaternary andesite flow from Mount Adams. This flow, which is covered by McDonald Ridge Drift at its upper end, is deflected by the cone to produce a distinct wake effect in the flow pattern. The cone, therefore, antedates the flow, as well as the drift. Although some cinder cones of Smith Butte Olivine Basalt appear fresher than the Snipes Mountain cone, probably most are of comparable age.

Late Quaternary intracanyon flows

Late Quaternary intracanyon olivine basalt flows, ex-

truded from vents beyond the area of study, occupy portions of the White Salmon River and Klickitat River valleys. The flows are extensive, but only a small part of them are included within the area mapped.

The White Salmon River valley, in the vicinity of Trout Lake, is filled with numerous, thin (1.5 to 3.0 m), medium-gray, vesicular flows of porphyritic olivine basalt (Fig. 22). The flows entered the White Salmon valley here from the western tributary of Cave Creek and continued south almost to the Columbia River. Sheppard (1964) suggested that the flows were erupted from a shield volcano in the northern part of the Willard quadrangle; however, Hammond (1973) has shown that Lemei Rock (Sec.11, T.6N., R.8E.) was the source. Similar flows are exposed in a few places along the floor of Trout Lake Creek northwest of Trout Lake, indicating some flows may have entered the White Salmon River valley from that tributary. Near Trout Lake the intracanyon flows cover weathered till of inferred White Salmon age (Fig. 42), and are mantled by a mudflow having a radiocarbon age of 5,070 years B.P. (Fig. 61).

The Klickitat River canyon, north of Surveyors Creek (Sec.14, T.8N., R.12E.), contains many flows, 2.5 to 4.0 m thick, of medium-gray, porphyritic pyroxene-olivine basalt. The flows were extruded from a vent north of Mount Adams and entered the Klickitat canyon from the tributary valley of West Fork. The basalt flows postdate the large canyon-filling flow

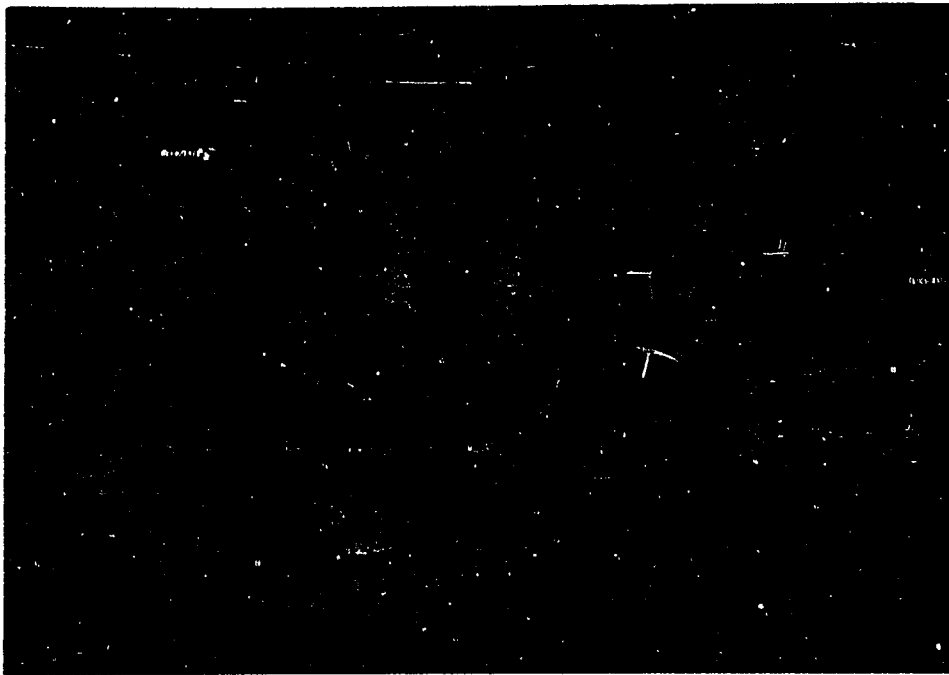


Figure 22. Intracanyon flow of olivine basalt in the White Salmon River valley (SW 1/4, SE 1/4, Sec.15, T.6N., R.10E.

of Mount Adams andesite, which occupies the Klickitat River valley east of Mount Adams, and they terminate in a reentrant cut by the Klickitat River in the earlier canyon fill.

Mount Adams Volcano

Mount Adams (3744 m) is a partially dissected stratovolcano of middle to late Quaternary age (Fig. 23). It is built chiefly of andesite lava flows, but includes interbedded layers of volcanoclastic debris. The lava flows and interflow clastic layers, as well as the products of closely associated satellitic vents on the upper slopes of the volcano, are referred to here as the Mount Adams Volcanics.

The Mount Adams Volcanics cover approximately 700 km² and attain their greatest aggregate thickness in the main cone of the volcano. Projection beneath the volcano of the landscape developed on adjacent pre-Mount Adams rocks (see below), indicates an aggregate thickness for the Mount Adams Volcanics of about 2200 to 2400 m. Thus, Mount Adams compares closely with nearby Mount Rainier volcano in total volume of extruded material (cf. Fiske and others, 1963, Pl. 1).

Topography buried by Mount Adams

Buried peaks and ridges. Prominent peaks and ridges bordering Mount Adams that are composed of pre-Mount Adams rocks range in altitude from about 1200 to 1800 m. The highest such peaks lie north and west of the volcano and, on



Figure 23. Mount Adams, altitude 3744 m, from the southwest.

average, stand about 400 m higher than bordering peaks on the south and east. Erosional lowering of these older summits during growth of Mount Adams, particularly those south and east of the volcano, probably was minimal, as suggested by the relatively little-eroded forms of nearby pre-Mount Adams shield volcanoes such as King Mountain and Jungle Butte (immediately east of study area). Therefore, peaks and ridges on the buried landscape probably are similar in altitude to bordering peaks which escaped burial.

Relief. The landscape covered by the earliest flows from Mount Adams was one of moderate to high relief. The initial relief was greatest beneath the north and west quadrants of the volcano where early Mount Adams flows were extruded onto a terrain of early to middle Tertiary lava flows and volcanoclastic rocks. However, it probably was less than the present relief (800-1200 m along major valleys) northwest of Mount Adams owing to accelerated valley deepening in that area by late-Quaternary glaciers.

Early Mount Adams lava that flowed to the south and southeast spread over a landscape of moderate relief. Valley-filling olivine-basalt flows and coalescing shield volcanoes of early to middle Quaternary age already had covered much of the rugged late-Tertiary landscape in that area before the first Mount Adams flows were extruded. Except along major valleys, exposed areas of the basalt south and southeast of Mount Adams show only slight to moderate erosion. Therefore,

the terrain bordering Mount Adams in that area (relief generally less than 300 m) has not been modified greatly since the beginning of Mount Adams time, and probably resembles the topography covered by early southward-flowing lava from Mount Adams.

Fiske and others (1963, p. 67) estimated the early relief at Mount Rainier by determining the difference in altitude between the bases of the oldest Rainier flows and the highest remnants of older rocks. They identified as the oldest flows those which filled canyons cut into pre-Rainier rocks, but which today form ridges and peaks. Canyon-filling flows, they reasoned, can be recognized by their exceptional thickness (more than 150 m), which results from ponding against valley walls. They interpreted the present position of such flows along divides as evidence for a very long interval of erosion following extrusion of the flows.

The method of Fiske and others, however, cannot readily be applied on the south slope of Mount Adams. Owing to the relatively low relief of the pre-Mount Adams landscape in that area, the early valley-filling lavas which flowed south from Mount Adams were not ponded in deep canyons, so are not exceptionally thick. Furthermore, because the modern valleys are not deep enough to expose older rocks beneath the andesite, estimates of the early relief must be measured from the deepest exposures in probable early flows. The figure obtained, therefore, excludes an unknown thickness of andesite

below the base of the exposure.

With these uncertainties in mind, an approximate, minimum estimate for the early relief east of Mount Adams can be made. The flows underlying The Island appear old because they are cut by canyons 200 to 300 m deep. Near the east end of The Island, Big Muddy Creek has cut down through 240 m of andesite to an altitude of 1100 m (3500 feet). Approximately 3.5 km northeast, the Yakima Basalt upland immediately west of the Klickitat River reaches an altitude of 1450 m (4755 feet). Therefore, the relief of the pre-Mount Adams surface in that area was at least 350 m.

Lava flows of the lower slopes

Viewed from most directions, the profile of Mount Adams consists of two principal elements: a steep-sided main cone, and a broad, gently sloping base that extends outward 12 to 14 km beyond the volcano's summit. The transition between the main cone and the lower slopes, though indistinct in places, generally lies between 2000 and 2500 m (6600 and 8200 ft), and coincides approximately with the apparent outer limit of abundant interflow clastic layers. Below this level, the lower slopes of the volcano are underlain primarily by andesite lava flows which dip generally away from the summit area at 8° or less. The flows range in thickness from 25 m to at least 150 m, but the thickest flows are not completely exposed.

Field description. In both areal and stratigraphic

distribution, the flows of the lower slopes appear remarkably similar. Typically, they are medium gray to bluish gray or pinkish gray, except near their tops where they are often dark gray owing to abundant glass in the groundmass. Where original flow tops are preserved, commonly the uppermost 2 to 8 m is moderately to highly vesicular. All flows are porphyritic to some degree; most are highly porphyritic and include conspicuous phenocrysts of plagioclase and pyroxene.

Jointing is common in the flows and takes several forms. Platy jointing, parallel to the flow surface, is well developed in the upper 5 to 10 m of most flows, and causes the andesite to break into flat slabs 1 to 20 cm thick (Fig. 24). The joints are more widely spaced with depth and give way to blocky or massive andesite below (Fig. 25). Crude columns occur locally in many flows, but well-developed columnar jointing generally occurs only in the thickest flows.

Although most flows forming the lower slopes of Mount Adams are very similar in appearance, there are a few notable exceptions. Most of these are glass-rich varieties which are much darker than typical Mount Adams andesite. One particularly distinctive flow lies between Bacon Creek and Dry Creek on the southeast slope of the volcano. Although not confined to a well-defined valley, the flow is one of the longest on the southeast slope. It is exposed only along logging roads where it is dark gray to black, rich in glass, and contains relatively few phenocrysts. In many places it is penetrated



Figure 24. Closely spaced platy joints in andesite flow from Mount Adams. Joints shown are 1 to 8 cm apart at depth of 3 m below flow top.

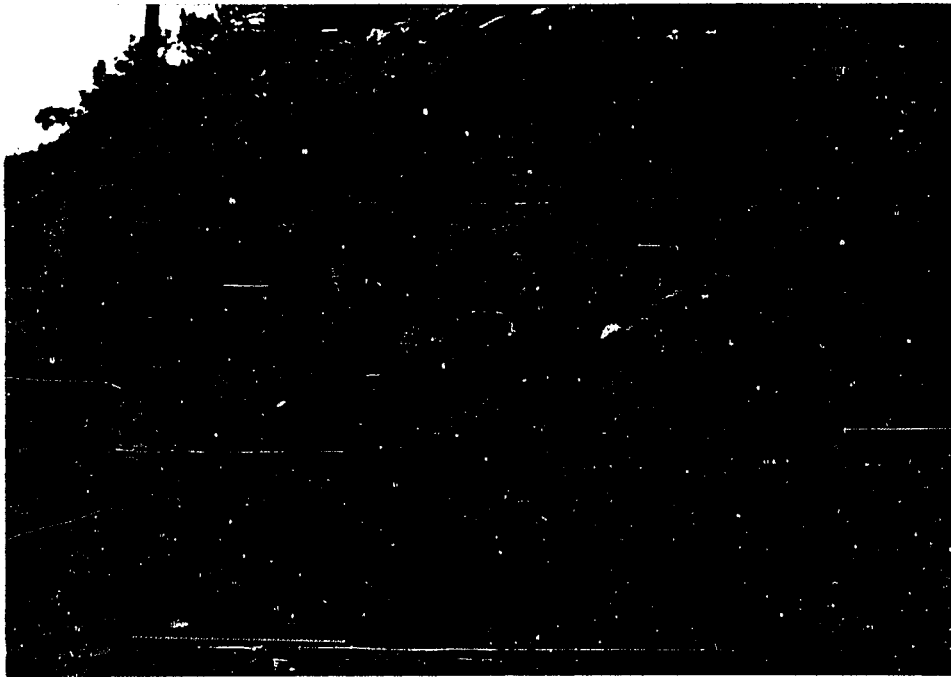


Figure 25. Blocky jointing in Mount Adams andesite. Joints are 6 m below flow top (not visible).

by numerous, closely spaced, irregular fractures that cause it to crumble when struck with a hammer. Because of its unusual appearance, the flow is not readily recognized as a Mount Adams flow. However, careful examination of roadcut exposures shows that the glass-rich lava grades downward into lava that more closely resembles typical Mount Adams andesite.

Discrimination and mapping of flows. Discrimination and mapping of individual flows on the lower slopes of the volcano are hampered by the highly uniform character of the Mount Adams lava. Most flows are so similar in their lithologic characteristics that they cannot easily be distinguished from one another, nor can they be correlated between widely separated outcrops. Flow mapping, therefore, frequently involves tracing of individual flows along valley-side exposures where physical continuity can be established. However, even this procedure is not always successful because the continuity frequently is obscured by widespread sliderock deposits and dense forest.

Broad, relatively little-dissected uplands separate the major valleys on the south slope of Mount Adams. Flow mapping in these upland areas must be done primarily from surface exposures. Although there may be very little lithologic contrast between flows, flow boundaries can sometimes be located using certain geomorphic criteria. For example, drainage lines frequently follow flow margins, and in some places careful comparison of the adjacent rocks reveals

subtle lithologic discontinuities that normally might be overlooked. In other cases, the edges of some nonglaci-ated flows have sufficient relief to be traceable on aerial photographs as well as in the field.

Mapping of individual flows from Mount Adams is especially difficult where the flows have been glaci-ated. Therefore, with the exception of two small, postglacial flows, the principal flows on the south slope of the volcano are differentiated only where they extend beyond the border of the McDonald Ridge Drift (Pl. 1).

Form and distribution of flows. Much of the lava extruded on the south slope of Mount Adams appears to have spread as relatively broad flows or lava sheets, without strong topographic control. This pattern is most evident in the case of surface flows on the broad intercanyon uplands. By tracing the margins of these flows, where they extend beyond the drift border, it can be shown that many of the flows terminate along a relatively broad front (Pl. 1). Older flows beneath the upland surface, however, are visible only in bordering valley-side exposures, so that their distribution must be inferred from less direct evidence.

The flows exposed in valley walls are generally less than 60 m thick. Although good exposures are limited, the thickness of these flows can sometimes be estimated from steplike valley-side profiles, and from the vertical spacing

between isolated outcrops of glassy, rubbly, scoriaceous, or platy lava, all of which are characteristic of flow tops where visible in surface exposures. The lack of exceptionally thick flows suggests that the lava was not confined to deep valleys but spread relatively freely.

Additional evidence for widespread flows is provided by the apparent correlation of some flows across valleys, from one upland region to the next. The difficulties of correlation described earlier notwithstanding, tentative correlation across valleys can sometimes be made by tracing a single flow upstream through discontinuous valley-side exposures, across the valley head, and downstream along the opposite valley side. Thus, it appears that the divides and uplands are simply remnants of a sequence of broad lava sheets which has been incised by radial streams.

The absence of thick, valley-filling flows within this sequence of broad lava sheets, suggests that canyon cutting was minimal during the time spanned by their eruption. Although a few intracanyon flows have been identified on the south flank of the volcano, all occupy existing valleys. Therefore, the succession of flows exposed in divides and valley sides on the south slope of the volcano probably accumulated within a relatively short period of time prior to the cutting of major valleys,

Klickitat River intracanyon flow. The longest single flow on the south half of Mount Adams is a thick intracanyon

flow that occupies the Klickitat River valley east of the volcano. The flow entered the Klickitat valley at the mouth of Big Muddy Creek and flowed south to its terminal position 28 km from the volcano summit, as measured along the path of the flow. Lava also spread upstream along the Klickitat valley for about 3 km to a point 1.2 km north of Surveyors Creek. Incision of the flow by the Klickitat River did not begin immediately, but followed an interval of lateral stream migration, as suggested by remnants of abandoned sinuous channels and meander scars on the flow surface (secs. 13, 14, 24, 25, T.7N, R.12E.). Subsequent incision of the flow by the Klickitat River produced a narrow V-shaped inner gorge.

Exposures of the flow in the walls of the inner gorge are as much as 150 m high, but the base of the flow is not visible. In most respects the lava is typical of andesite seen elsewhere on the south flank of Mount Adams. Columnar jointing, however, is unusually well developed, and below a depth of about 25 m the flow is composed entirely of long, vertical columns 0.5 to 1.0 m in diameter. The columns are capped by both massive and platy lava which grades upward to a vesicular top.

Sheppard (1967b) suggested that the flow was extruded from the southeast flank of Mount Adams. Although several Mount Adams flows extended far down the southeast slope of the volcano, none entered the Klickitat valley. However, the

Klickitat River intracanyon flow can be traced to the mouth of Big Muddy Creek, directly east of the volcano, where eastward-flowing lava from Mount Adams entered the Klickitat River valley.

Latest eruptions. The youngest lavas on the lower slopes of Mount Adams are several fresh, blocky flows that lie on the northwest, northeast, east and south flanks of the volcano. Most were extruded from vents near the base of the main cone and spread downslope for several kilometers. The largest, covering about 15 km², are several overlapping flows from Red Butte on the northeast flank of Mount Adams.

Two other recent flows lie within the study area on the south and east sides of the volcano. The larger, which is also the younger of the two, is the A.G. Aiken Lava Bed (Fig. 26). The flow erupted near the base of South Butte cinder cone at about 2120 m (7000 ft) and flowed 6.5 km south as a long, narrow, steep-sided lava tongue. It is 0.8 km wide at its widest point and ranges in thickness from 15 to 40 m. The flow consists largely of lava rubble and angular lava blocks 10 cm to 2 m in diameter (Fig. 27). The flow rubble is largely stabilized and shows little sign of weathering. Although sparsely vegetated, it supports scattered shrubs and trees. Lichens cover generally less than 30 percent of the surface.

A similar lava flow, which erupted near Goat Butte on the



Figure 26. South side of Mount Adams and A.G. Aiken Lava Bed. Heavily forested lower slopes of the volcano are underlain by earlier lava flows from Mount Adams.

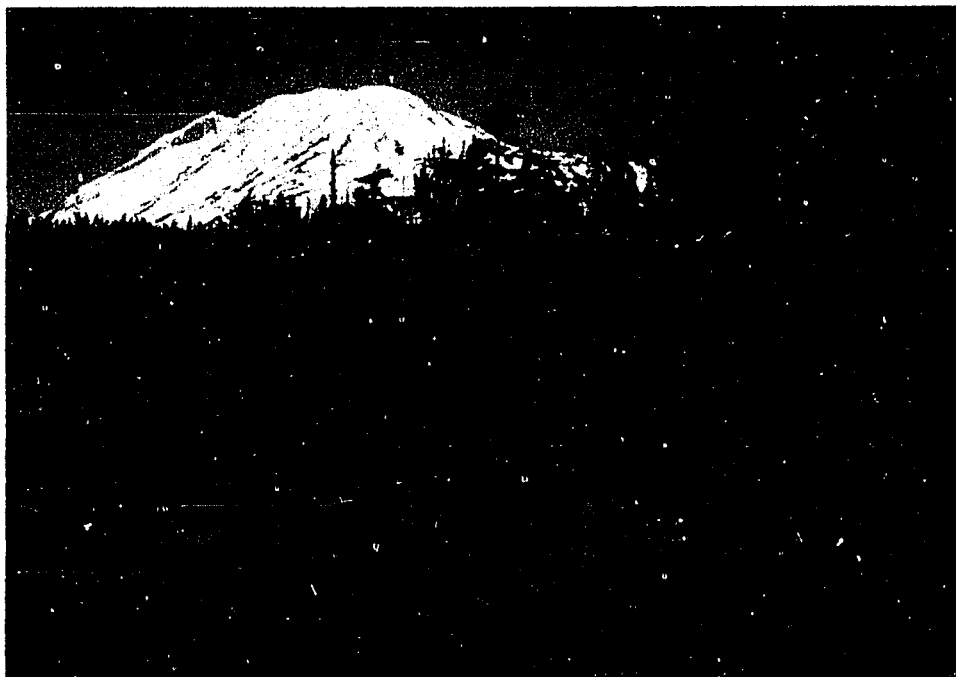


Figure 27. Blocky surface of A.G. Aiken Lava Bed. Mount Adams in background.

east flank of Mount Adams, flowed east approximately 5.5 km along Cunningham Creek to a point where it blocked and formerly ponded Swamp Creek, as shown by a little-dissected deposit of lake silt on the floor of the tributary valley. Surface blocks on the flow are stabilized, weathered, and commonly have a lichen cover exceeding 50 percent. Development of soil and forest cover also is much more advanced than on the A.G. Aiken Lava Bed. Therefore, the Cunningham Creek flow, although comparatively young, significantly predates the A.G. Aiken Lava Bed.

The main cone

The main cone of Mount Adams rises steeply to a broad summit area approximately 1600 m above the lower slopes of the volcano. The flows and clastic interbeds which form the main cone are best exposed in the precipitous cirque headwalls above Klickitat and Rusk glaciers. Although lava flows dominate the section, interbedded layers of clastic debris are common, and locally thick.

The lava flows of the main cone generally are less than 15 m thick. Dips commonly are 15° to 25°, but locally reach 35°. Flows examined are all pyroxene andesite and closely resemble the andesite flows on the lower slopes of the volcano. The main-cone flows, however, commonly are reddened by oxidation and locally altered by fumarolic activity.

Interflow breccia layers consist of angular clasts, 2 cm to 1 m in diameter, in a matrix of widely variable proportion.

Some of the breccias are completely unsorted and unstratified. Others contain occasional sorted lenses and partings of coarser or finer clasts, together with thin streaks of brecciated lava, which impart a crude stratification to the deposit. In most breccias, however, clasts of massive lava are common, and sometimes dominant, whereas pumice fragments are minor, and volcanic bombs are rare. Because the volcano probably has been mantled with snow and ice for much of its history, it seems likely that many of the breccias were produced by explosive shattering of lava erupted onto snow (Wise, 1968, p. 84; Fiske and others, 1963, p. 74), or were deposited as lahars generated by mixing of highly brecciated lava with meltwater.

Alteration of rocks in the main cone is sporadically distributed and affects lava flows and clastic layers alike. The most widespread form of alteration involves oxidation of magnetite to hematite in the groundmass of some flows, which produces colors ranging from pale red to very dark red. Hydrothermally altered and solfatarized rocks crop out at several localities in the cliffs above Klickitat and Rusk glaciers, and high on the northwest side of the main cone they appear as irregular bodies of exceptionally light-colored rock. Although most of the outcrops are inaccessible, fragments of the altered rock are common in drift carried by Klickitat and Rusk glaciers. One of the largest bodies of altered rock lies between 2745 m (9000 ft) and 3172 m

(10,400 ft) near the upper end of Battlement Ridge, which borders Klickitat Glacier on the north. Judging from the large volume of rock affected, the alteration probably reflects proximity to a major conduit. Some fumarolic activity continues today. Occasionally, when a light breeze is blowing downvalley, a distinctly sulfurous odor can be detected near Klickitat Glacier.

Compound structure of the main cone and the Mount Adams Fault. Viewed from the south, the main cone of Mount Adams has a relatively narrow, symmetrical profile (Fig. 28). Viewed from the west (Fig. 29), however, the main cone has a broad, irregular profile that consists of a central summit closely flanked on the northwest and on the south by two subordinate summits. The multiple summits are strongly suggestive of a compound structure, produced by lateral shifting of the vent over short distances.

The separate summits, of course, could have formed by partial destruction of a single, larger summit area. The northwest summit, known as The Pinnacle (farthest left in Fig. 29), may have formed in this way. Flows underlying The Pinnacle are steeply dipping, as are the flows exposed on the northeast side of the central summit. Upward projection of these flows suggests that all of them could have been erupted from a single vent which lay approximately 210 to 240 m above, and slightly north of the present summit cone. Projections of this kind, however, can give only a rough



Figure 28. Mount Adams from the south showing relatively narrow, symmetrical profile.

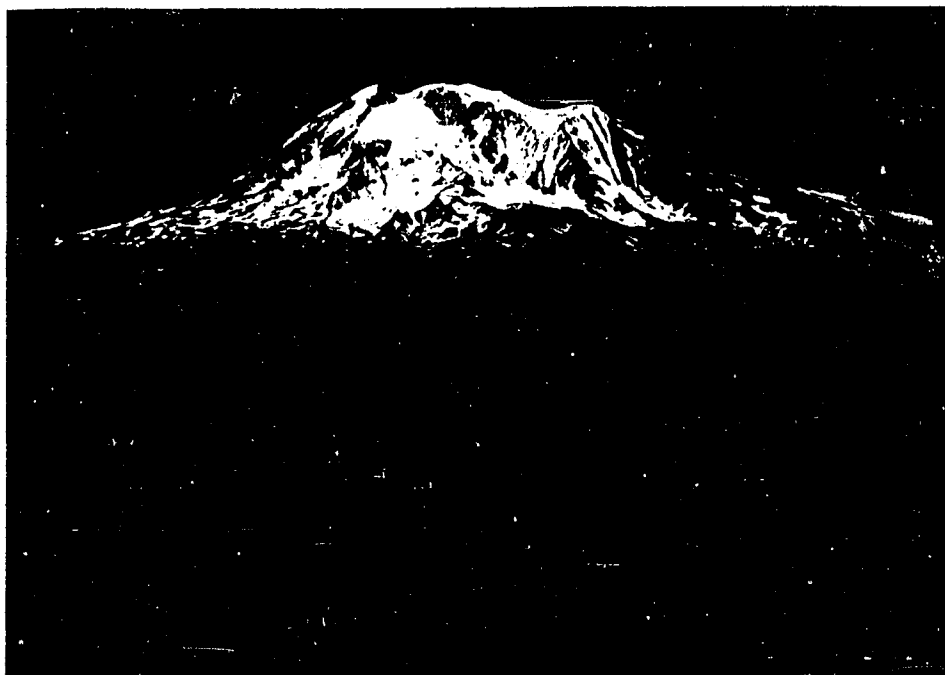


Figure 29. Mount Adams from the west. Broad, irregular profile reflects compound structure of the main cone.

estimate of the former height of the volcano because most outcrops show only an apparent dip, and the inaccessibility of many outcrops makes it impossible to obtain true dips.

The southern summit, on the other hand, appears to have been formed by eruptions from a separate vent. Although properly oriented exposures are lacking, flows underlying the central and southern summits appear to have opposing dips, and between the two summits the dips of flows from the southern summit seem to flatten out. Furthermore, the form of the southern summit strongly resembles that of a separate cone, truncated on its east side and banked against a larger central cone. Petrographic comparisons of flows underlying the central and southern summits have not been made; however, flows beneath the southern summit generally are darker than those of the central summit area. The cone forming the southern summit probably postdates the central cone, judging from its somewhat less modified form and the apparent reduction of dips on flows from the southern vent in the region between the two summits.

The south flank of the main cone, known as Suksdorf Ridge, flattens out abruptly at an altitude of 2867 m (9400 ft) and forms a low, rounded shoulder (extreme right of Fig. 29). This was the site of repeated eruptions of lava which spread across the lower slopes of the mountain. Most of the flows were erupted relatively late in the history of the volcano. Some of the flows unconformably overlies much

older Mount Adams flows, and others are interstratified with tills farther downslope on the south flank of the volcano.

The three separate eruptive vents inferred to comprise the main cone of Mount Adams are located on a line that trends approximately N18°W; consequently, their position may be fault controlled.

Evidence for a major fault beneath Mount Adams is provided by a linear, east-facing scarp on the lower slope of the volcano south of the main cone (Fig. 30). The south end of the scarp lies in the NE 1/4, Sec.9, T.7N., R.11E. From there, the scarp can be traced N22°W nearly 3 km to the SE 1/4, Sec.32, T.8N., R.11E., where it becomes indistinct. The scarp is 30 to 60 m high for most of its length. Its base is obscured by sliderock which, in places, extends nearly to the top of the scarp, but outcrops near the top expose highly fractured and brecciated Mount Adams andesite. In some outcrops, the andesite exhibits platy jointing, and near the top of the scarp it is glassy and scoriaceous, resembling flow tops seen elsewhere on Mount Adams. Thus, the scarp appears to mark a fault, upthrown on the west, that offsets lava flows underlying the south slope of Mount Adams.

If the scarp is projected upslope, with a very slight bend at about 2300 m (ca. 7600 ft), it passes directly under the summit of Mount Adams, and coincides with the line along which the multiple vents of the main cone are grouped.



Figure 30. View north along scarp of Mount Adams Fault. Summit of Mount Adams, behind trees in background, lies directly on northward projection of fault.

Therefore, probably the scarp, as well as the vents, lie along a common fault. If so, the fault is at least 10 km long and is a major structural feature in the Mount Adams area. It is referred to hereafter as the Mount Adams Fault.

Some eruptions from Mount Adams during a relatively early stage of cone building may have occurred from one or more vents which lay east of the present summit. The evidence is inconclusive, and consists of two isolated outcrops of lava flows and breccias which do not appear to be related to vents located in the summit area. Flows and breccias having discordant dips are exposed between 2100 m (6900 ft) and 2400 m (7900 ft) on the west side of the large cirque that lies north of the Ridge of Wonders (Fig. 31), and other exposures occur at the east end of The Spearhead, between 2380 m (7800 ft) and 2500 m (8200 ft), on the northside of Battlement Ridge (Fig. 32). The outcrops are not readily accessible, so that the angle and amount of dip must be estimated visually. Although the direction of exposure makes such estimates deceptive, these rocks apparently dip away from a source located between the two outcrops, approximately 2 to 3 km eastsoutheast of the present summit.

Radial dikes. The flows underlying the Ridge of Wonders are cut by numerous dikes that stand out prominently from the talus-covered cirque headwall on the north side of the ridge. The most prominent dikes, shown in Figure 33, are composed of medium-gray, porphyritic rock that resembles the andesite

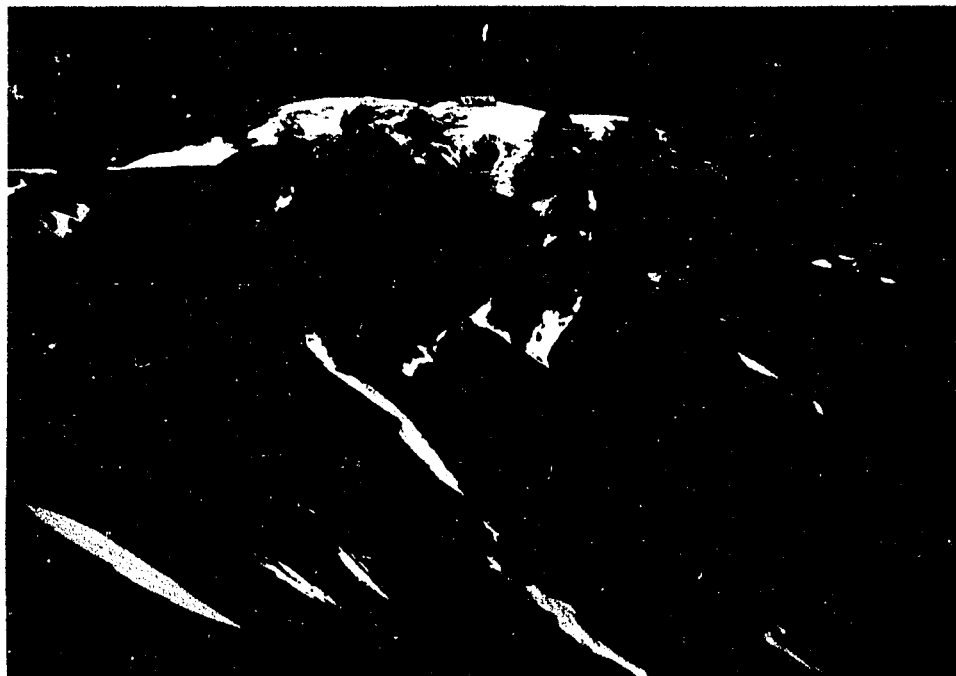


Figure 31. Breccias and flows exposed at west end of Ridge of Wonders. Direction of dip suggests that vent lay east (right of photo) of present summit. Sequence is overlain unconformably by thin, dark flows (upper left) extruded much later from cone which forms lower, south summit (left of center in background) of Mount Adams.



Figure 32. Steeply dipping breccias and flows underlying The Spearhead. Direction of dip is strongly discordant with that of flows extruded from vents near the present summit (background).

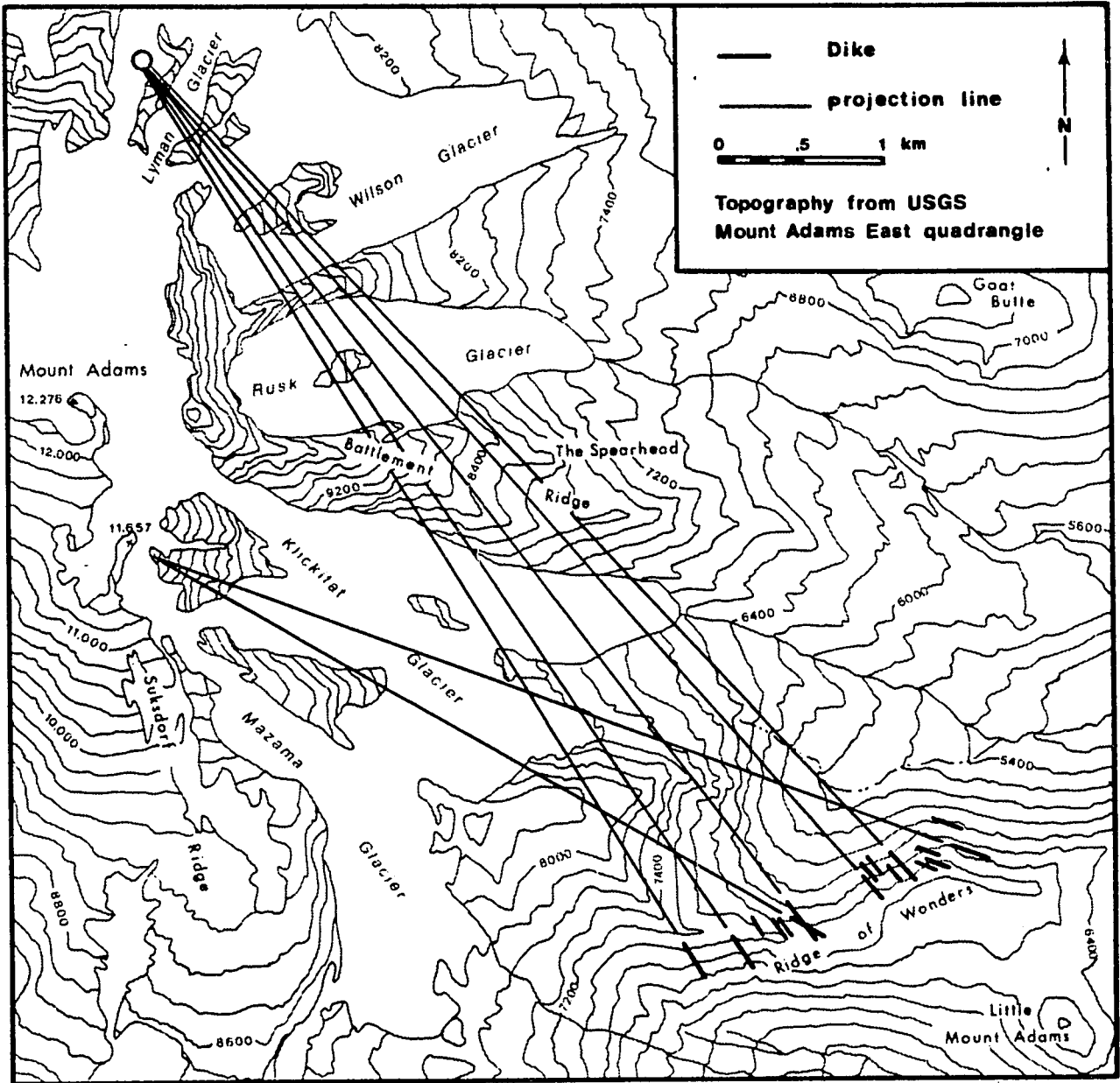


Figure 33. Radial dikes of the Ridge of Wonders and some projected foci.

of most lava flows erupted from Mount Adams. Although the dikes generally converge to the northwest, they do not have a common focus, and may be of two different ages.

One group of dikes strike $N33^{\circ}-41^{\circ}W$, so that if projected northwest along strike, they lie well to the east of the present summit. Because the dikes do not converge strongly, their projected points of intersection are extremely sensitive to even the slightest variations in strike. Nevertheless, the projections of five of the dikes focus sharply at a point on Lyman Glacier (Fig. 33). The focal point lies outside the study area; however, reconnaissance on the north flank of the volcano shows no evidence of a vent there. The focal point lies only a short distance east of the line along which the principal eruptive centers of the main cone are located. The projections (not shown) of several other dikes in this group intersect in the general area of the lower Klickitat Glacier. Projections of other dikes in this group intersect randomly with those discussed above within the triangle formed by the two ends of the Ridge of Wonders and the focal point located on Lyman Glacier.

The dikes of this first group antedate the cone that forms the lower, south summit (upper end of Suksdorf Ridge) of Mount Adams. Flows from the cone, which unconformably overlie older rocks exposed in the Ridge of Wonders (Fig. 31), truncate two dikes of this group.

A second, and perhaps younger, group of dikes strikes

N60°-73°W, and appears to radiate from the lower, south summit of Mount Adams. Projections of two of these dikes are shown in Figure 33.

The projections shown in Figure 33 are based on the assumption that the dikes are linear. Fiske and Jackson (1972) showed that dikes intruded in volcanic edifices other than symmetrical cones may be curved, owing to the influence of gravitational stress fields within the volcano. However, the dike pattern of Figure 33 does not match the pattern predicted by their work for a cone having north-south elongation. Furthermore, dikes of the second group probably are straight because their projections focus near a known vent.

Summit cone. The latest eruptions in the summit area of Mount Adams produced a small lava and cinder cone that forms the highest point on the volcano (Fig. 34). The summit cone ranges in height from about 75 m on its north side to 150 m on its southwest side where it is draped over the steep west flank of the older main cone below. Although the east flank of the summit cone has been partly cut away by the summit ice cap, the cone, as a whole, shows relatively little dissection, and it is topped by a well defined crater (Fig. 35). The crater rim is asymmetric, and is about 45 m higher on the north side than on the south side.

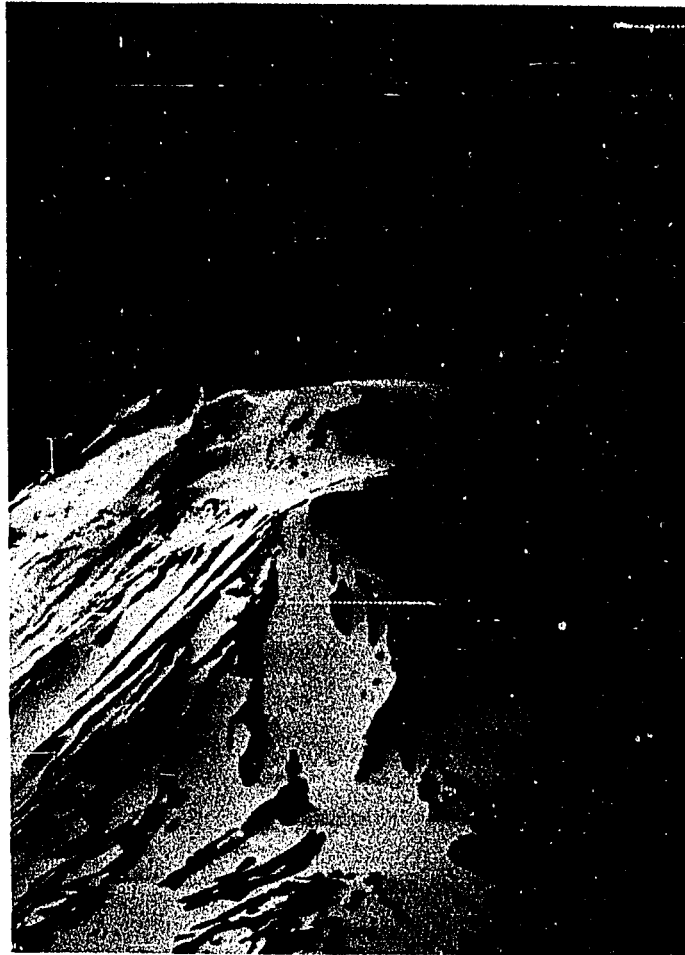


Figure 34. Broad summit area of Mount Adams with snow-covered summit cone near center. Mount Rainier in distance.



Figure 35. Snow and ice filled crater of the summit cone. Mount Hood on the skyline.

The cone is composed of both lava and cinders; however, the proportion of each is difficult to estimate because much of the cone is covered by snow and ice. The south and southwest slopes of the cone, which are snowfree in late summer, are mantled by loose, angular lava rubble and cinders. A few thin flows are exposed on the east flank of the cone and are composed of dark gray to black, porphyritic lava resembling glass-rich varieties of the Mount Adams andesite on the lower slopes of the volcano. The flows, and much of the lava rubble on the north and east sides of the crater, show evidence of fumarolic activity. The lava is mottled and stained with sulfur, and in many places it is coated or completely impregnated with a soft, chalky, white clay. However, no evidence of thermal activity was observed, either as vapors or as vents melted in the ice and snow occupying the crater.

Parasitic cones

During a late stage of activity, when construction of the main cone was largely completed, flank eruptions from Mount Adams produced a number of parasitic cones that encircle the volcano between 1500 and 2300 m. Three of the cones lie within the study area.

The best preserved of the parasitic cones is Little Mount Adams (Fig. 36) which rests on the west end of The Island, southeast of Mount Adams. It is a steep-sided, symmetrical cone, 120 m high, with a sharply defined summit



Figure 36. North side of Little Mount Adams
cinder cone.

crater. The cone is composed primarily of coarse ash, scoriaceous lapilli, and occasional bombs and blocks. However, several thin brecciated flows are exposed in isolated outcrops on the south flank of the cone, and lava agglutinate forms prominent outcrops along the east, south, and west sides of the crater rim. Along the east base of the cone, cinders from Little Mount Adams overlap a lateral moraine and striated rock surfaces that probably date from the last glaciation. Although the cone must be relatively young as indicated by its freshness of form, its slopes have been modified sufficiently by gullying and nivation to suggest an age of at least a few thousand years.

Goat Butte (Fig. 37), which lies directly east of Mount Adams on the north edge of the study area, is the largest as well as the oldest and most dissected of the parasitic cones. The lower part of the cone contains numerous flows which are exposed around its base, whereas the upper part of the cone is composed largely of tephra. The flows, which are best exposed on the deeply eroded south flank of the cone, are composed of medium-dark-gray, strongly porphyritic, olivine basalt. Most of the tephra layers are red, brown, and black cinders and coarse ash; however, yellowish-orange lapilli tuff forms a prominent outcrop on the south flank of the cone. The tuff is a mixture of yellowish-brown, vesicular lapilli, euhedral crystals of olivine and pyroxene, and yellowish-orange glass. The glass has a relatively low



Figure 37. Strongly eroded southwest flank of Goat Butte as viewed from terminus of Rusk Glacier.

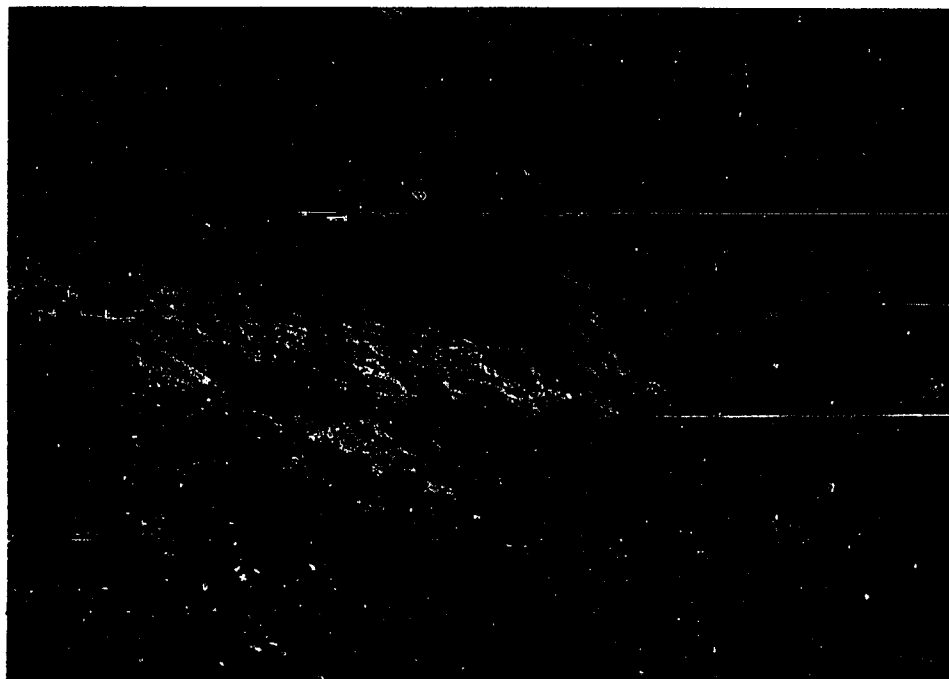


Figure 38. Stratified lapilli tuff exposed on the south flank of Goat Butte.

index of refraction (generally less than 1.55) and probably is palagonite. Stratification in the tuff is weakly to moderately well developed (Fig. 38), and the strata dip generally away from the summit of Goat Butte. The relatively resistant tuff has been weathered and eroded along vertical joints to produce a cluster of spires and ridges that stand 30 to 45 m above the south slope of the cone.

The overall form of Goat Butte has been strongly modified by erosion. The south base of the cone has been truncated, probably during a former expansion of Rusk Glacier, and the upper slopes of the cone are so deeply scalloped by nivation hollows that the summit crater can no longer be distinguished. The nature and intensity of modification indicate that the cone is at least pre-Neoglacial in age, and that probably it dates to the last glaciation. The presence of palagonite tuff on the south flank of the cone suggests that some eruptions from Goat Butte may have occurred during a period of expanded glaciers and snow cover, possibly at a time when Rusk Glacier was banked against the base of the cone.

South Butte (Fig. 39), which lies at 2300 m (7500 ft) on the south side of Mount Adams is primarily a tephra cone, but several brecciated flows are exposed near its base and in small outcrops near its summit. Although the cone probably postdates the last glaciation, it is moderately dissected, and its east flank has been truncated by Gotchen Glacier.



Figure 39. West side of South Butte cinder cone on the south flank of Mount Adams.

Most of the dissection probably occurred during the late Holocene when Gotchen Glacier had thickened sufficiently to encroach on the east flank of the cone.

Petrography

The lava flows from Mount Adams are as similar in thin section as they are in the field. Nearly all are highly porphyritic and contain, in decreasing order of abundance, phenocrysts of plagioclase, hypersthene, augite, and olivine. The phenocrysts, which comprise 25 to 40 percent of the rock, are set in a groundmass of plagioclase laths, pigeonite, magnetite, and varying amounts of glass. Glomeroporphyritic clots are common in many flows, and may include any of the phenocryst minerals. Most flows have a model color index between 30 and 36, and an average plagioclase composition less than An_{50} . Thus, in the absence of chemical data, they are classified as andesite.

The flows differ principally in the texture of their groundmass. Most flows are pilotaxitic to intersertal, and generally contain less than 20 percent glass (Fig. 40). Some flows, however, are hyalopilitic and contain as much as 40 percent glass (Fig. 41). The hyalopilitic flows typically are thin, and are significantly darker than most other Mount Adams flows. The A.G. Aiken Lava Bed and the young flow bordering Cunningham Creek, which are among the latest flows erupted from Mount Adams, are of this kind. Alignment of the plagioclase laths is common in flows which are holocrystalline



0 .05 mm

Figure 40. Pilotaxitic flow of hypersthene-augite andesite from Mount Adams. Divide-forming flow exposed in valley wall of Hellroaring Creek. Plane light.



0 .05 mm

Figure 41. Hyalopilitic flow of hypersthene-augite andesite from Mount Adams. A.G. Aiken Lava Bed. Plane light.

or nearly so, and is particularly strong in flows having platy jointing.

The mineralogy of the Mount Adams flows varies little. Many of the mineralogical characteristics of flows examined in this study match closely the data reported by Sheppard (1967b) which were obtained from study of a single flow.

Plagioclase forms subhedral phenocrysts, generally 0.5 to 3.0 mm long; however, glomeroporphyritic clusters of plagioclase may be as much as 5 mm across. Most grains are clear, polysynthetically twinned, and normally zoned; many grains also show superimposed oscillatory zones. The composition of zoned grains ranges from An₄₀₋₅₅ (cores) to An₂₈₋₄₀ (rims). However, as has been reported for the lavas of Mount Rainier (Coombs, 1936, p. 175; Fiske and others, 1963, p. 87), the plagioclase phenocrysts in a single flow are of widely diverse character. Thus, most sections also contain phenocrysts which are untwinned and unzoned, partly corroded, or contain poikilitic inclusions of pyroxene. Plagioclase microlites in the groundmass generally are less than 0.3 mm long and have an average composition of about An₃₂.

Hypersthene occurs both as moderately pleochroic, subhedral phenocrysts 0.3 to 2.0 mm long, and as reaction rims on olivine. The optic angle, determined from U-stage measurements, is negative and ranges from 60° to 62°. Many hypersthene phenocrysts are rimmed with tiny granules of

pigeonite where the phenocrysts are in contact with the groundmass. Somewhat less common are hypersthene phenocrysts having wide overgrowths of augite.

Phenocrysts of augite, which are nearly as abundant as those of hypersthene, occur as pale-green, irregular prisms 0.3 to 2.5 mm long. Many of the grains exhibit lamellar twinning. The optic angle is positive and ranges from 47° to 50° . As with hypersthene, augite phenocrysts often are surrounded by rims of granular pigeonite.

A few scattered phenocrysts of olivine, generally 0.2 to 1.5 mm in diameter, are present in most sections. They have subhedral form and sometimes are strongly resorbed. Some of the olivine grains are surrounded by randomly oriented hypersthene, as reported by Sheppard (1967b, p. C57), but many are not.

Pigeonite occurs in the groundmass as tiny, anhedral grains having a positive optic angle of approximately 10° . As described above, pigeonite also occurs as small granules that rim hypersthene and augite where these two minerals are in contact with the groundmass. This relationship, which was noted by Sheppard (1967b, p. C56), appears to be a ubiquitous feature of the Mount Adams flows; however, it is seen more commonly in pilotaxitic than in hyalopilitic flows.

An opaque mineral, probably magnetite, occurs as small, anhedral grains in the groundmass and as inclusions in the ferromagnesian minerals. Occasionally, it forms small

phenocrysts up to 0.4 mm across. In reddened flows, the groundmass magnetite is oxidized to hematite.

The only flows of the Mount Adams Volcanics that differ strikingly from the description above, are strongly porphyritic, olivine-bearing flows which were extruded from Goat Butte on the east flank of Mount Adams. Olivine, which forms large (≤ 5 mm), subhedral grains, is the principal phenocryst; augite, and occasionally, hypersthene also occur as phenocrysts. In two sections examined, not a single plagioclase phenocryst was found. The exceedingly fine-grained groundmass is composed chiefly of tiny grains of plagioclase, granular clinopyroxene, and magnetite. Lacking chemical data, the rock is classified as olivine basalt on the basis of its high modal color index (C.I. ≈ 60).

Age and stratigraphic relationships

In the absence of an adequate number of radiometric dates, the age and eruptive sequence of the Mount Adams Volcanics cannot be closely established. However, some approximate limiting dates for various stages of the volcano's activity can be set. The best evidence comes from two localities: the Klickitat River intracanyon flow east of Mount Adams, and the south slope of the volcano where lava flows are interbedded with till.

Age of the Klickitat River intracanyon flow. Evidence for the age of the Klickitat River intracanyon flow comes

both from field relationships and from a radiometric date. The flow probably antedates the oldest glacial deposits in the area, but the evidence is contradictory.

Near the mouth of Big Muddy Creek, subdued lateral moraines and deeply weathered till of the White Salmon Drift can be traced to the edge of the flow, but not onto its surface. Although dense forest and a lack of exposures on the flow surface in that area make surficial geologic mapping difficult, the relationships suggest that the flow overlies, and therefore postdates, the White Salmon Drift. This interpretation is supported by the present canyon-bottom position of the flow, which normally is a characteristic of relatively young flows. It might be argued that the depth to which the flow has been incised by the Klickitat River (nearly 150 m) points to a greater age for the flow. However, incision must, nevertheless, have followed retreat of the ice because the steep-sided, V-shaped inner gorge shows no sign of glacial erosion.

Evidence suggesting a pre-White Salmon age for the flow is provided by several exposures of deeply weathered gravel which rest on the flow approximately 2.2 km downstream from the confluence of Big Muddy Creek and the Klickitat River. Although it cannot be demonstrated that the gravel is of glacial origin, the depth and degree of weathering suggest that the gravel is at least as old as the White Salmon Drift.

A radiometric age obtained from the flow supports

second interpretation. A sample of the flow, collected approximately 10 m below its top near the mouth of Big Muddy Creek, was dated by Geochron Laboratories (Cambridge, Mass.) using the K-Ar method. The determination was made using the whole rock, after removal of pyroxene, and yielded an age of $400,000 \pm 100,000$ years (Geochron R-2483). Although the procedure used by Geochron is not well suited for rocks younger than 1 million years, the age probably is reliable within the assigned range of error (R.H. Reesman, personal communication, 1973). Thus the weight of the evidence favors a pre-White Salmon age for the flow, and a tentative age of 400,000 years is assigned.

The position of the Klickitat River intracanyon flow in the eruptive sequence of Mount Adams is not clear. Two possibilities exist:

(1) The intracanyon flow is an extension of one of the flows that underlie the broad divides and upland regions on the lower slopes of the volcano. It originated as a broad flank flow that spread eastward across the lower slope to where it spilled into the Klickitat Valley near the mouth of Big Muddy creek.

(2) The flow was channeled eastward to the Klickitat Valley along one of the deep radial valleys cut into the earlier lower-slope flows. Possible remnants of the intracanyon flow lie along the bottom and sides of the valley of Hellroaring Creek; however, the relationships have been

obscured by subsequent glaciation of the valley and by the McDonald Ridge Drift.

The first case implies that the flows underlying the broad divides on the lower slopes of the volcano are also approximately 400,000 years old. The second case, however, implies that eruption of the intracanyon flow followed a period of valley cutting during which the earlier flows of the lower slopes were incised by radial streams. Therefore, the early flows, now exposed in the walls of the radial valleys, are much older than $400,000 \pm 100,000$ years. In either case, a minimum age of 400,000 years is indicated for the early flows that form the lower slopes of Mount Adams.

Age of the Suksdorf Ridge flows. The youngest flows from Mount Adams that lie within the study area were erupted from Suksdorf Ridge on the south flank of the volcano. Most of the flows, which postdate the bulk of the main cone, were extruded at about 2860 m (9400 ft) and flowed south for about 13 km. The youthful age of the flows is indicated by the comparatively slight modification of lower Suksdorf Ridge by Mazama, Gotchen, and Crescent glaciers.

The best evidence for the age of the youngest Suksdorf Ridge flows occurs on the lower slope of the volcano where the flows intertongue with lavas of the Smith Butte Olivine Basalt, and with two late-Pleistocene tills. The stratigraphic relationships between the flows and the tills are

shown by the map and cross-section of Figure 42. Erosion of the flows in this sequence is slight and vertical exposures are few. However, the morphology of the flows is sufficiently fresh that the stratigraphic relationships can be determined from the patterns of overlapping flow margins.

Deeply weathered White Salmon till, tentatively regarded to be of Salmon Springs age is exposed in the valley of the White Salmon River along segment A-B of the cross-section line. Traced to the north along transect A-B-C-D, the till passes beneath a flow of Smith Butte Olivine Basalt, 4 to 6 m thick. Approximately 1 km farther north, the basalt flow is overlapped by a thick blocky flow of andesite from Mount Adams. The overlapping relationship is clear because the andesite flow terminates along a steep front 20 to 80 m high. Continuing north along transect A-B-C-D, the andesite flow is covered by a thin flow of olivine basalt, which is, in turn, overlapped by another andesite flow, 15 to 25 m thick. Northward from point C, the andesite flow is overlapped by relatively fresh McDonald Ridge till, which is correlated broadly with the Fraser Drift of the Puget Lowland. Thus, if the two tills are correlated correctly with the glacial chronology of the Puget Lowland, then the flows from Suksdorf Ridge and the flows of Smith Butte Olivine Basalt were erupted during the Olympia Interglaciation.

The youngest Mount Adams flow in the sequence shown in Figure 42 is the A.G. Aiken Lava Bed (described earlier).

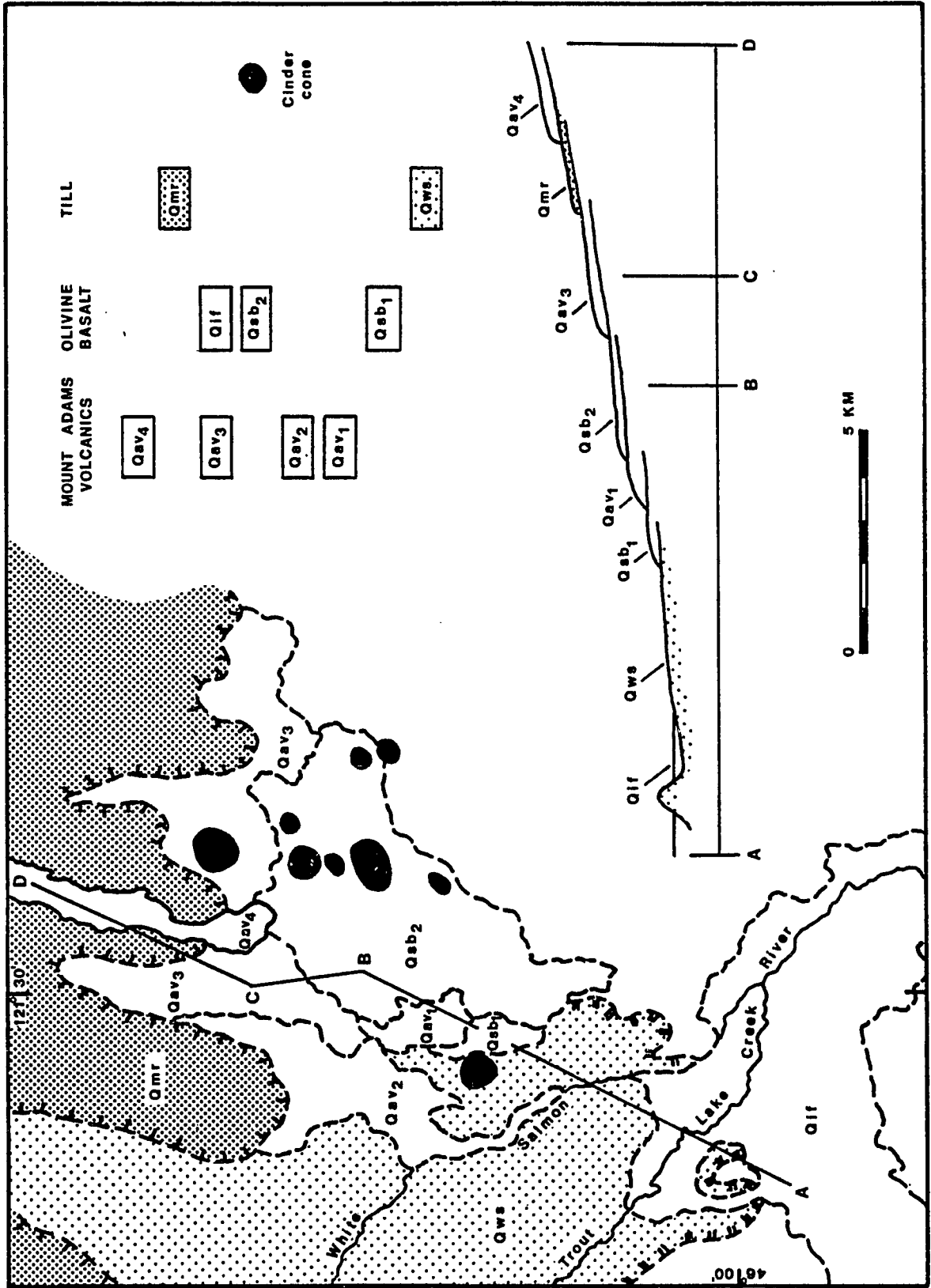


Figure 42. Interstratified lava flows and tills on the south slope of Mount Adams

The flow clearly postdates the McDonald Ridge Drift. Near its lower end, the flow overlies McDonald Ridge till, and near its upper end, it rests directly on striated and polished rock surfaces of McDonald Ridge age (Fig. 43).

A maximum age for the A.G. Aiken flow can be established more closely from its stratigraphic relationship to tephra layers in the adjacent surficial deposits. Four distinct layers of pumiceous ash and lapilli are present in surficial sediments on both sides of the flow; however, only the uppermost layer occurs on the flow surface. The ages and sources of the two uppermost layers are unknown, but field and petrographic characteristics of the third layer indicate that it may be set-Y tephra from Mount St. Helens, which has been assigned an age of 3000 to 4000 years (Mullineaux and others, 1972).

A minimum age for the A.G. Aiken flow was determined from ring counts on trees growing on the flow surface. Counts made on cores obtained with a Swedish increment borer showed 286 rings in the oldest tree sampled. However, because the rough, blocky surface of the flow provides so few opportunities for seedlings to become established, the age of the flow may be substantially greater than that of the oldest tree growing on its surface.

Summary. Based on the data presented in this section and earlier in this paper the following general statements



Figure 43. A.G. Aiken Lava Bed resting on unweathered striated and polished rock surface of McDonald Ridge age.

can be made regarding the age of the volcano:

(1) The early eruptions from Mount Adams followed a period of widespread olivine-basalt volcanism that probably continued at least to the middle Pleistocene.

(2) The flows underlying the broad divides and uplands on the lower slopes of the volcano are at least 400,000 \pm 100,000 years old.

(3) The main cone of the volcano, with the exception of Suksdorf Ridge, had reached a height sufficient to accumulate large glaciers prior to White Salmon (Salmon Springs?) time.

(4) The youngest flows erupted from Suksdorf Ridge on the south flank of the volcano are of post-White Salmon and pre-McDonald Ridge (Olympia?) age.

(5) Parasitic cones and small lava flows were erupted on the flanks of the volcano in Holocene time. The maximum age of the A.G. Aiken Lava Bed has been set at 3000 to 4000 years, and the flow may be the youngest erupted from Mount Adams.

SURFICIAL DEPOSITS

Tephra

Occurrence and nomenclature of layers

Tephra deposits, all probably Holocene, can be found throughout the study area. However, the deposits are best preserved and most easily studied in alpine meadows between 1700 and 2100 m (ca. 5500 and 7000 ft) where they occur as usually distinct layers up to 30 cm thick. Soil cohesiveness in this region is relatively high, owing to the constantly moist condition of the ground, so that reworking of tephra by wind is prevented. Tephra deposited on the dry, lower slopes south and east of the volcano commonly is reworked by wind and the layers are indistinct.

Exposures in the alpine meadows sometimes show as many as 8 to 10 tephra layers in the uppermost meter of section (Fig. 44). However, many of these layers are thin, discontinuous, and contain an admixture of other sediments. Therefore, they may consist of reworked and redeposited tephra eroded from upslope. At many localities, tephra layers are exposed in the walls of small gullies cut by snow meltwater. The streams flowing in these gullies are moving tephra eroded from such sites, and are redepositing it in shallow basins and meadows a short distance downslope. Locally, tephra derived from shallow exposures is spread on the ground surface, and is being moved downslope by mass-wasting and

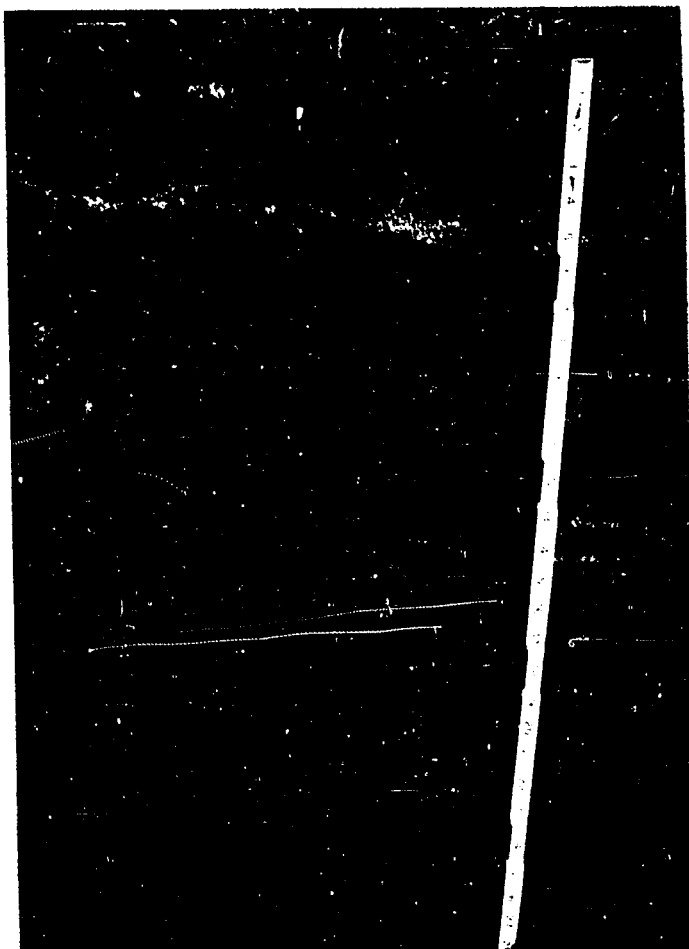


Figure 44. Pumiceous tephra layers in pit exposure at Bird Creek Meadows, 1890 m (6200 ft), south flank of Mount Adams. Some layers are discontinuous and show evidence of reworking.

unconcentrated flow. Reworking of tephra by such processes probably has been equally effective in the past, so that some of the layers seen in meadow exposures may consist of redeposited older tephra.

Four distinct and persistent tephra layers can be recognized at widely separated localities on the southeast flank of Mount Adams. They are shown in the composite section of Figure 45. The layers are designated by arbitrary symbols in the manner used by Crandell and others (1962) at Mount Rainier. This scheme permits additions to the sequence without changes in nomenclature. Symbols were selected from the Greek alphabet to avoid any possible confusion with the numerous tephra layers already recognized at Mount St. Helens (Crandell and Mullineaux, 1973) and at Mount Rainier (Mullineaux, 1974), which carry English-letter designations. Although the section shown in Figure 45 is generalized from measurements made at widely separated localities, it closely resembles the section exposed along U.S. Forest Service road N80, between 1650 m (5440 ft) and 1720 m (5640 ft) on the south side of Hellroaring Creek, where layers γ , δ , and ϕ are particularly well displayed.

Field description

The tephra layers shown in Figure 45 consist primarily of small pumiceous lumps, glass shards, and crystals. The characteristics by which these layers are most easily distinguished in the field are summarized in the diagram.

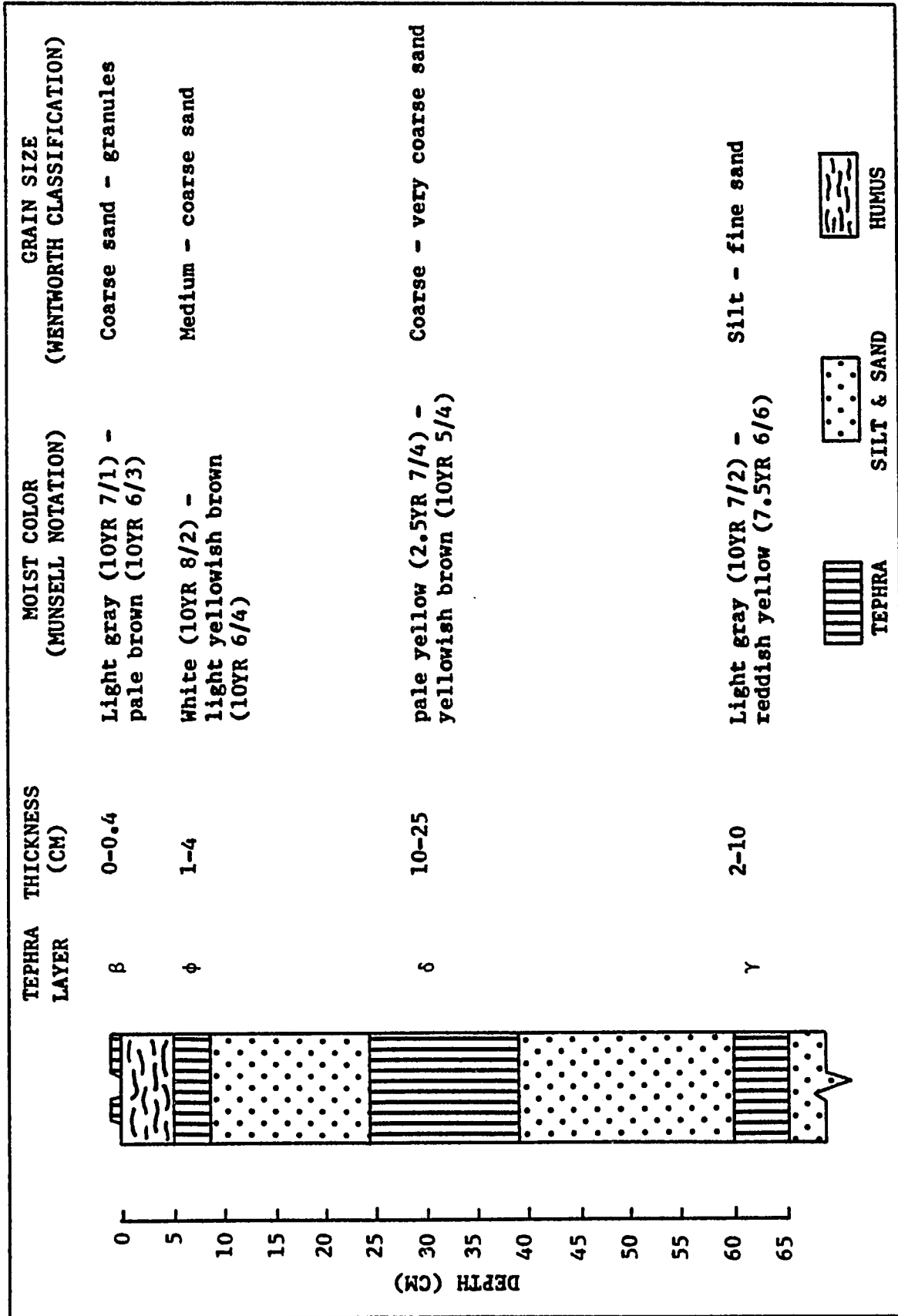


Figure 45. Principal tephra layers on the south flank of Mount Adams and their field characteristics.

Depth, thickness, grain size, and color of the layers proved to be the most useful distinguishing features, and in sections where most or all of the layers are present, they usually are reliable. Depth and thickness of the layers generally were measured on slopes of less than 15°. Colors are described in terms of the Munsell notation, and were determined from moist samples.

Petrographic analysis

Samples of the tephra were examined with a petrographic microscope to determine (1) relative abundance of ferromagnesian minerals, (2) minimum refractive index of ferromagnesian minerals, and (3) refractive index of glass. These characteristics were selected for study because they have proven to be among the most useful distinguishing features of pumiceous tephra (Wilcox, 1965).

Preparation of samples for petrographic examination followed the procedure outlined in Figure 46. The procedure is designed, insofar as possible, to concentrate mineral grains which occur as phenocrysts in the pumiceous fraction, because such grains clearly are of nondetrital origin. The bulk samples were first vibrated for approximately five minutes in an ultrasonic cleaner to loosen and remove weathering products and other fine-grained contaminants. Samples composed mostly of coarse ash and lapilli were then washed on a 0-phi (1 mm) screen, dried, and manually cleaned under low-power magnification to remove any nonpumiceous

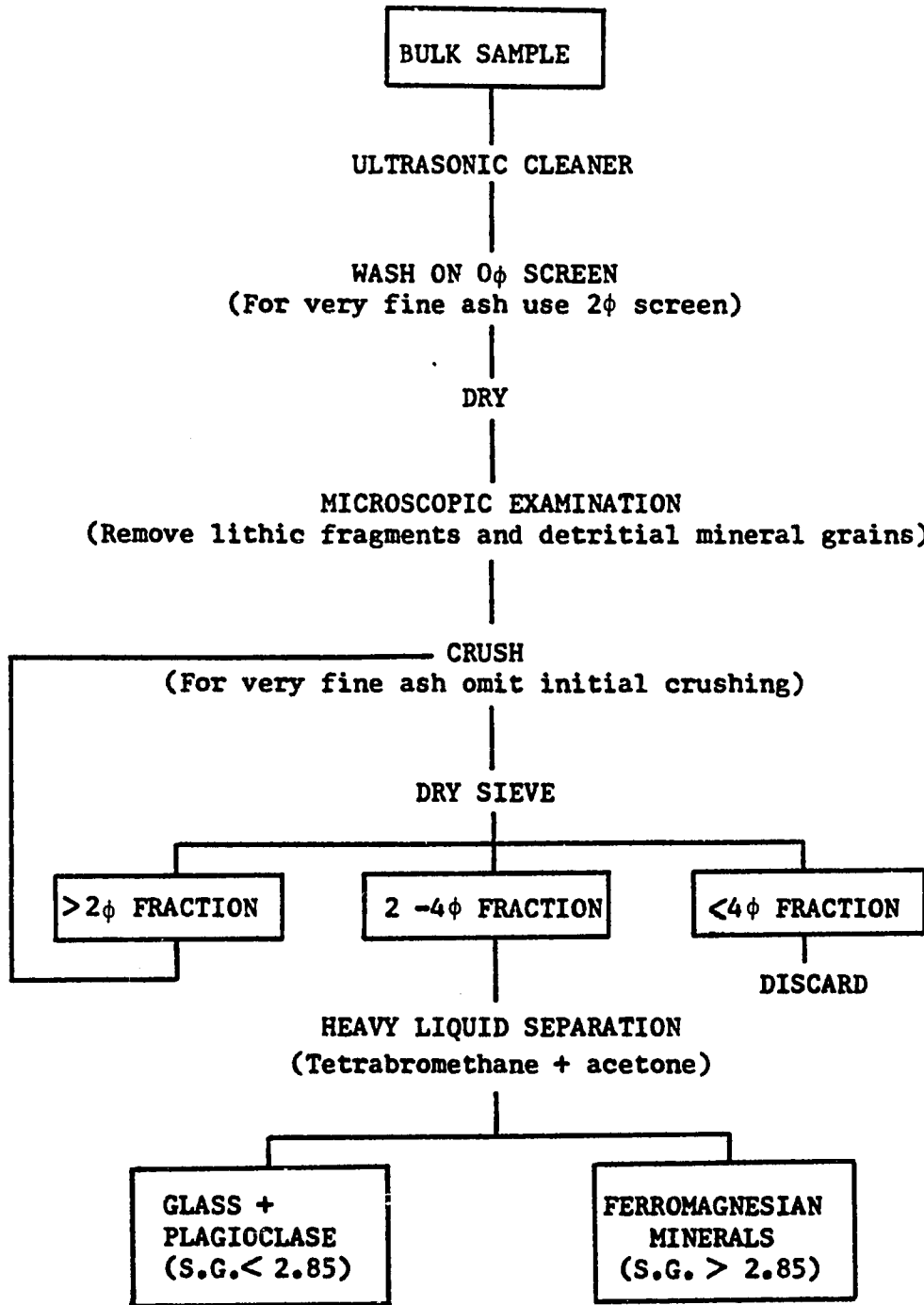


Figure 46. Laboratory flow sheet for preparation of tephra samples for petrographic examination.

particles remaining. Samples of relatively fine ash (nearly all particles less than 1 mm) were washed on a 4-phi screen in order to retain enough of the sample for further processing. The cleaned samples were crushed (except for very fine-grained samples) and sieved to segregate grains of suitable size for petrographic study. Finally, the samples were centrifuged in heavy liquid and split into a glass and plagioclase-rich fraction (S.G.<2.85), and a ferromagnesian-rich fraction (S.G.>2.85).

Petrographic data for tephra layers γ , δ , and ϕ are shown in Table 1. Mineral abundances were determined with the aid of a mechanical stage by counting individual grains in slide-mounted samples. The data are presented, however, in broad categories of relative abundance owing to the difficulties inherent in preparing a truly representative mount. Refractive-index measurements were made on a single-axis stage in sodium light, using the Becke-line method. Immersion oils, differing in index by increments of .004, were used to bracket the indices of the mineral grains and the glass.

Sources

Layer γ shows no detectable trend in thickness or grain size within the study area, and probably was erupted from a distant source. On the basis of both field and petrographic criteria, layer γ tentatively is correlated with the Mazama ash of Powers and Wilcox (1964). The thickness and grain

TEPHRA LAYER	FERROMAGNESIAN MINERALS			GLASS
	MINERAL	ABUNDANCE	MINIMUM REFRACTIVE INDEX (n_x)	
ϕ	Hypersthene	P	1.691 - 1.695	1.496 - 1.500
	Hornblende	S	1.659 - 1.667	
δ	Hornblende	P	1.663 - 1.667	1.488 - 1.496
	Cumingtonite (?)	P	1.643 - 1.647	
	Hypersthene	M	N.D.	
γ	Hypersthene	P	1.683 - 1.687	1.499 - 1.511
	Hornblende	S	1.667 - 1.671	
	Augite	S	N.D.	

P = Principal constituent (> 30% of Fe-Mg minerals)
 S = Secondary constituent (2-30% of Fe-Mg minerals)
 M = Minor constituent (< 2% of Fe-Mg minerals)
 N.D. = Not determined

Table 1. Petrographic characteristics of principal tephra layers.

size of layer γ compares closely with values that would be expected for the Mazama ash in the Mount Adams area, based on studies of Mazama ash at Mount Rainier (Mullineaux, 1974, p. 29). The age of the Mazama ash, as determined at its source, is about 6600 years (Rubin and Alexander, 1960, p. 161). Thus, if the correlation suggested above is correct, layer γ is a useful stratigraphic marker in the Mount Adams area for establishing limiting ages on other Holocene deposits.

Layers δ and ϕ show no pronounced variation in thickness or grain size on the south flank of the volcano; however, they appear to thicken and coarsen slightly to the west. Reconnaissance sampling west of Mount Adams suggests that layer δ , and possibly layer ϕ , continue with this trend farther west. Particularly striking in the mineralogy of layer δ is the presence of a pale, weakly pleochroic, optically positive amphibole, many grains of which do not go to complete extinction (cummingtonite?). In many respects layer δ resembles tephra-set Y which was erupted from Mount St. Helens Volcano (Mullineaux and others, 1972; Crandell and Mullineaux, 1973; Mullineaux, 1974), 54 km west of Mount Adams. Because cummingtonite-bearing tephra is known only from Mount St. Helens, layer δ is correlated tentatively with tephra-set Y. Layer ϕ resembles tephra layer W from Mount St. Helens, both in field characteristics and in mineral composition. However, because the refractive index

of hypersthene in layer ϕ is significantly lower than that reported for layer W (c.f. Mullineaux, 1974, p. 71), the relationship between these two tephra layers is unclear.

Layer β , which occurs as scattered pumice lapilli on or immediately below the ground surface, is discontinuous everywhere it was observed. It appears to be coarsest on the southwest flank of the cone but owing to limited opportunities for adequate sampling, its source was not determined.

Glacial Deposits

Deposits representing three separate episodes of glacier expansion in the Mount Adams area are designated here, from oldest to youngest, as the White Salmon, McDonald Ridge, and Big Muddy Creek drifts (Fig. 47). In most cases, the three drifts are readily distinguishable on the basis of distribution, morphology, and weathering characteristics. Specific criteria found most useful for differentiating the drifts are summarized in Table 2. Although soil profiles developed on the drifts were not studied in detail, general profile characteristics, particularly soil structure and the presence or absence of a textural B horizon, were especially useful for differentiating deposits of the two older drifts.

White Salmon Drift

Distribution and morphology. The White Salmon Drift is named for a weathered till that is exposed northeast of the White Salmon River in cuts along Forest Road N700 in secs. 35 and 36, T.7N., R.11E. White Salmon Drift is most widely distributed southwest of Mount Adams where it occurs primarily as thin (generally less than 2 m thick), discontinuous ground moraine between altitudes of 600 and 900 m (ca. 2000 and 3000 ft). Ground moraine shows little constructional form, and streams on its surface are sufficiently well integrated that no undrained depressions remain. End moraines are few; where preserved, they generally have broad, poorly

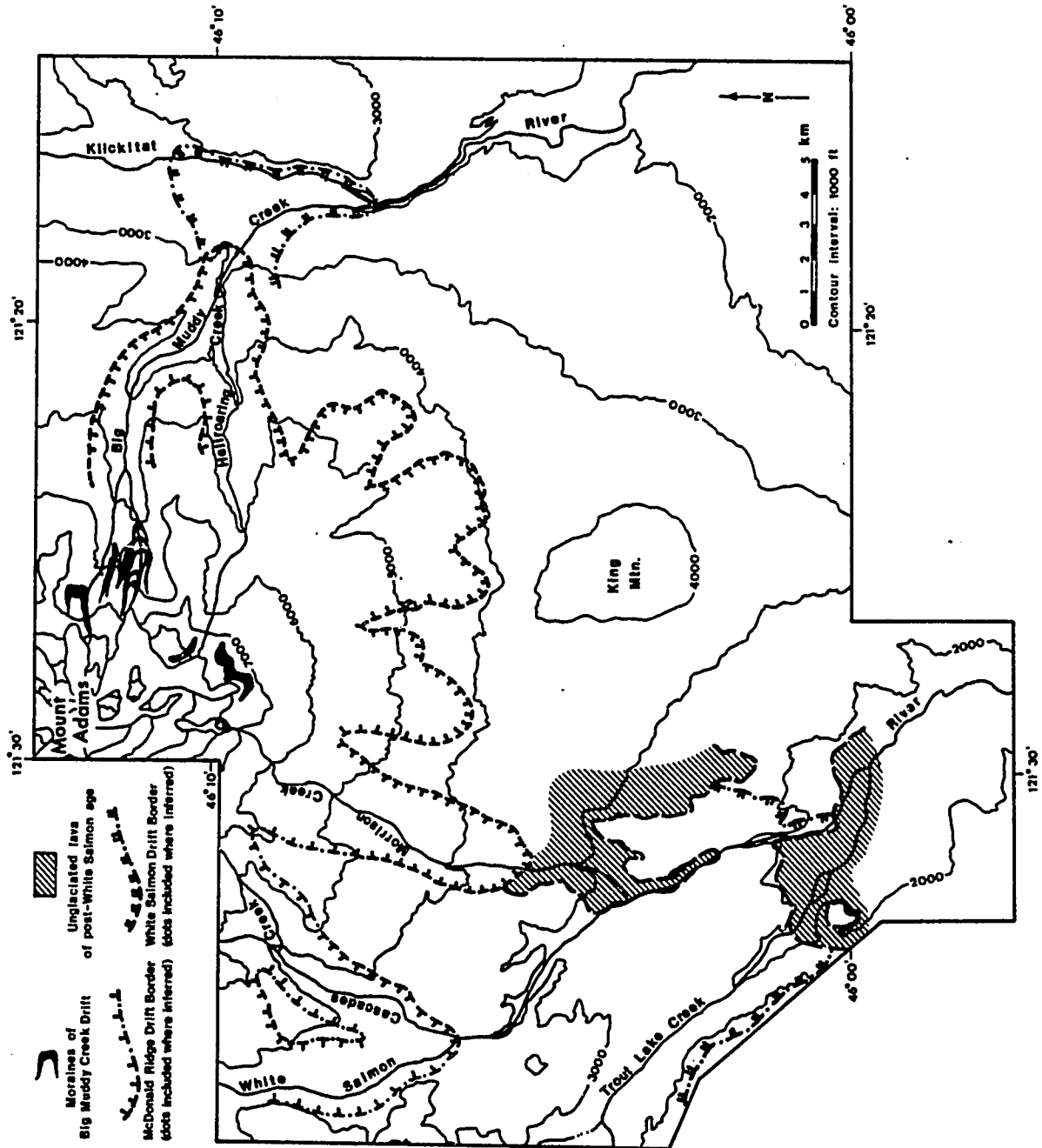


Figure 47. Drift borders and Neoglacial moraines

	White Salmon Drift	McDonald Ridge Drift	Big Muddy Creek Drift
Lower limit of drift	600 - 900 m	1000 - 1500 m	1520 - 1950 m
Moraine crests	Broad and poorly defined	Slightly rounded, but well defined	Sharp to very sharp
Depth of oxidation	2 - 3 m	0.8 - 1.3 m	0 - 15 cm
Condition of stones ¹ in weathering profile Percent firm Percent weathered Percent decayed	68 23 9	94 6 0	
Rind thickness of stones in weathering profile	1 - 2 mm	0 - 0.5 mm	absent
Soil characteristics Textural B horizon Structure	Weak, but discernible Coarse platy to subangular blocky	Absent None obvious	
Occurrence of tephra layer ^δ		Present on moraines	Absent from moraines

¹Condition defined as: Firm = cannot be broken by single, forceful hammer blow;
Weathered = intact, but broken easily with single hammer blow;
Decayed = largely disintegrated; cannot be removed intact.

Table 2. Criteria used to differentiate drifts.

defined crests and deeply gullied flanks.

White Salmon ground moraine covers the ridge separating the White Salmon River and Trout Lake Creek, and scattered patches of strongly weathered till of probable White Salmon age occur along the valley sides of Trout Lake Creek. The distribution of drift in this area suggests that ice in the White Salmon River valley overtopped the divide and may have merged with a glacier that advanced along Trout Lake Creek from a source farther west.

Near Trout Lake, the White Salmon drift border is buried beneath olivine basalt flows that entered the White Salmon River valley from a western tributary. However, downvalley projection of exposed segments of the drift border indicates that buried drift probably extends no more than 3.2 km south of the edge of the flows. White Salmon till partially covers a knob of Yakima Basalt that protrudes above the surface of the intracanyon flows in the SE 1/4, Sec.16, T.6N., R.10E., and is the southernmost exposure of till in the White Salmon valley.

Northeast of the White Salmon River, between Wickey Creek and Gotchen Creek, White Salmon Drift is overlapped by Smith Butte Olivine Basalt and by andesite flows from Suksdorf Ridge on Mount Adams (Fig. 42).

White Salmon Drift also occurs east of Mount Adams near the mouth of Big Muddy Creek on the west side of the Klickitat River valley. End-moraine remnants and exposures

of obvious till are confined to the valley side just above the surface of the Klickitat River intracanyon flow. The relationship there suggests that the drift may antedate the flow; however, a pre-White Salmon age for the flow is favored (p. 85). Although the drift border has not been mapped on the flow surface, an approximate limit of glaciation can be inferred from the distribution of moraine remnants and till patches on the valley sides.

Moraines and till of White Salmon age apparently are absent on the southeast slope of Mount Adams. Where not mantled with outwash or eolian sediments, unglaciated surfaces on Yakima Basalt and on County Park Olivine Basalt can be traced upslope to end moraines of the McDonald Ridge Drift. Possible White Salmon outwash occurs in shallow exposures along Dry Creek and its tributaries in Sec.13, T.7N., R.11E., just beyond the McDonald Ridge moraines. Its presence there suggests that White Salmon-age glaciers, although less extensive than those of McDonald Ridge time, advanced a short distance down the southeast slope of the volcano. The greater extent of glaciers on this part of the volcano during McDonald Ridge time may reflect changes in configuration of the catchment area for these glaciers, caused by eruption of the Suksdorf Ridge flows.

Outwash of White Salmon age cannot be identified with confidence. Strongly weathered gravel occurs as isolated patches beyond the limit of glaciation on the southeast flank

of the volcano and on the surface of the Klickitat River intracanyon flow. Similar gravel locally overlies White Salmon till northeast of the White Salmon River. However, because these deposits lack continuity and cannot be traced to moraines, a glacial origin cannot be demonstrated. Coarse gravel that may be recessional outwash of White Salmon age overlies weathered till on the east side of the White Salmon River in NE 1/4, SW 1/4, Sec.11, T.6N., R.10E. The gravel, which shows weathering comparable to that of White Salmon till (see below), underlies a nearly flat, terrace-like surface approximately 17 m above the river.

Nature and weathering of till. White Salmon till is exposed in a 10-meter-high roadcut through a lateral moraine near the mouth of Big Muddy Creek, and in numerous shallow roadcuts through ground moraine northeast of the White Salmon River (Fig. 48), between 600 and 900 m (ca. 2000 and 3000 ft). The till is pinkish gray to light brownish gray where fresh, but weathers to dark yellowish brown. Although oxidation commonly extends to depths of 2 to 3 m, oxidation to 8 m occurs in the exposure near Big Muddy Creek. Rinds developed on stones in the weathering profile commonly are between 1 and 2 mm thick. Faceted stones are common but striations rarely are preserved. More than half the stones in the upper part of the weathering profile are firm; however, many are crushed easily by a single hammer blow, and a few are totally disintegrated.

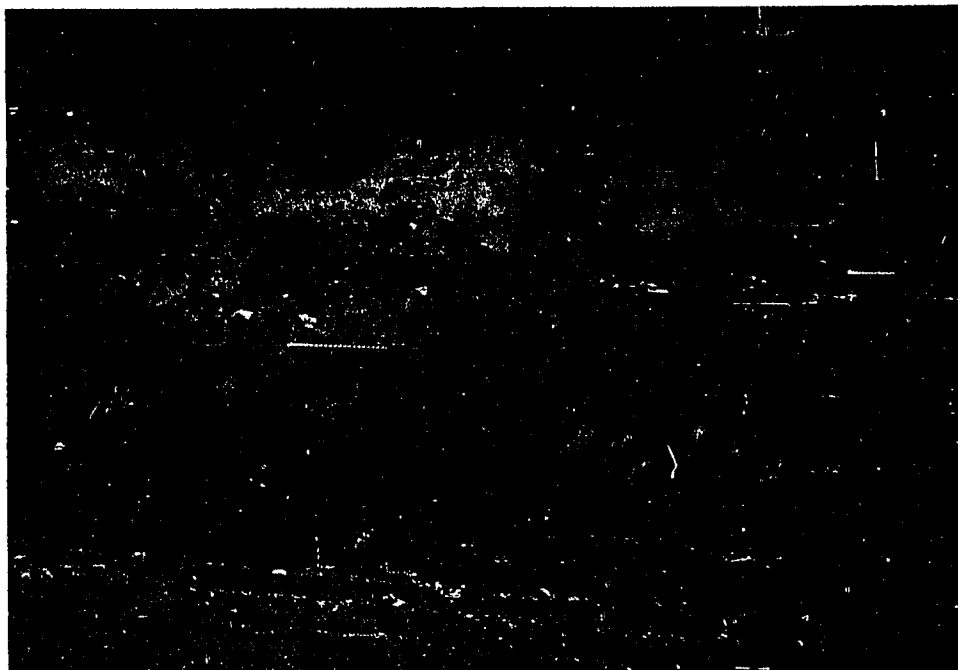


Figure 48. Strongly oxidized White Salmon till in roadcut northeast of the White Salmon River (NE 1/4, SW 1/4, Sec.35, T.7N., R.10E.). Oxidation here extends to base of exposure (3 m). Note distinct platy zone in upper part of exposure.



Figure 49. White Salmon till in exposure 1 km west of Trout Lake. Overlying silt is unusually thick at this locality.

Soil developed on White Salmon till is more variable in character than that developed on McDonald Ridge till, probably owing to greater variation both in parent material and in the effectiveness of post-depositional erosion and mass-wasting. Most horizons in the profile are either gravelly sandy loam or sandy clay loam. Typically, the profile is capped by a dark reddish-gray (5YR 4/2) A horizon, 10 to 25 cm thick. Beneath is a grayish-brown (10YR 5/2) to dark yellowish brown (10YR 4/4) B horizon, 60 to 100 cm thick. It contains sufficient clay to be slightly sticky and slightly plastic when wet; when dry, it becomes very hard. In many places the B horizon is characterized by a very coarse platy structure in its upper part, which is conspicuous in outcrops of White Salmon till (Fig. 48). Where absent, the platy structure usually is replaced by a weak subangular blocky structure. This material grades downward into fresh, structureless till that is both nonsticky and nonplastic.

Many exposures of White Salmon till are capped by a layer of yellowish-brown silt and fine sand, usually less than 30 cm thick. The silt, which probably is eolian, is widespread beyond the limit of McDonald Ridge Drift (Fig. 49). Where the silt caps White Salmon till, no soil is visible at its base. Because soil developed on the silt appears equally strong as that developed directly on White Salmon till, the silt may have been deposited shortly after recession of the White Salmon glaciers.

McDonald Ridge Drift

Distribution and morphology. The McDonald Ridge Drift is here named for a relatively fresh till exposed on McDonald Ridge in cuts along the Timberline Camp Road in secs. 1, 2, 10 and 11, T.7N., R.10E. The lower limit of McDonald Ridge till is marked by a belt of bulky, steep-sided end moraines that lie mostly between 1000 and 1500 m (ca. 3300 and 5000 ft). End moraines deposited by glaciers that occupied relatively shallow valleys on the south flank of Mount Adams form broad loops, in places having multiple crests. End moraines of glaciers that occupied deep canyons of Big Muddy, Hellroaring, and Cascades creeks occur as prominent, single-crested, lateral ridges along valley rims. Typically, end moraines of the McDonald Ridge Drift are 25 to 90 m high, steep-sided, and have slightly rounded, though well-defined crests (Fig. 50). With the exception of Morrison Creek valley, discernible end moraines inside the outer belt are few. Most are low, poorly defined, and their positions appear to be controlled by bedrock topography. Ground moraine forms a distinctly hummocky terrain behind the outermost moraines, but thins upslope and becomes discontinuous above 1800 m (ca. 6000 ft), where features of glacial erosion dominate.

The most detailed sequence of end moraines occurs in Morrison Creek valley where five separate end-moraine crests form partial or complete loops across the valley (Figs. 47



Figure 50. McDonald Ridge end moraine at Snowplow Mountain (NE 1/4, Sec.10, T.7N., R.11E.). Note steep outer flank and well-defined crest.

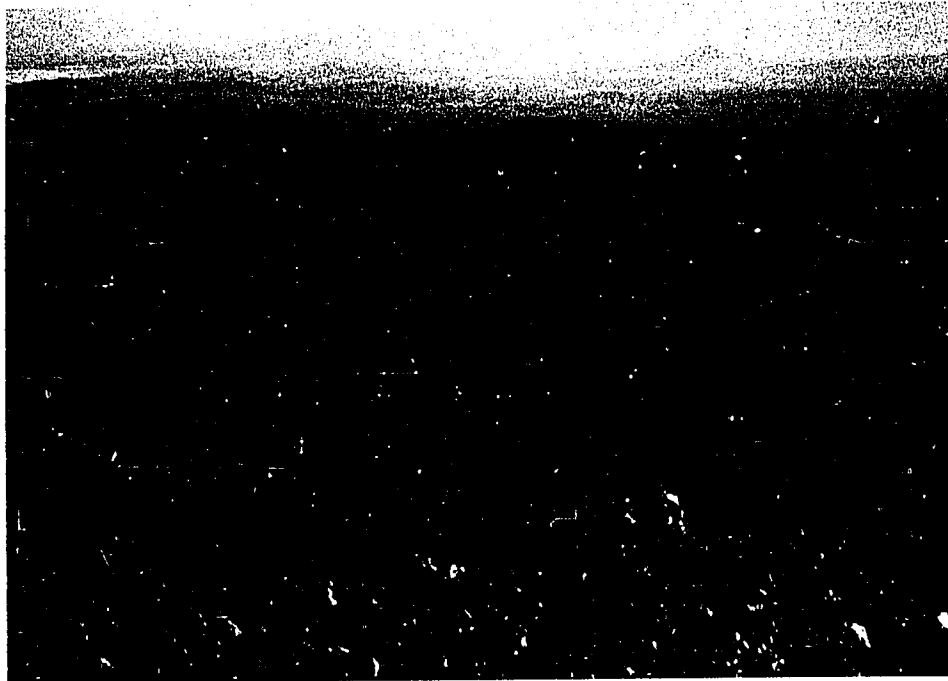


Figure 51. End moraines in Morrison Creek valley viewed from valley head. McDonald Ridge (upper left) consists of three, closely spaced, lateral moraines.

and 51). McDonald Ridge, which forms a prominent embankment along the east side of the valley, consists of three sharp-crested, lateral ridges that are closely grouped at their upper ends but diverge downvalley. The outer ridge is part of a nearly complete end-moraine loop that includes a single, large lateral moraine on the west side of the valley. The two inner ridges swing westward across the valley to form partial loops, but they have no counterparts on the opposite valley side. Two smaller, less sharply defined ridges lie on the valley floor behind the outer moraine complex. The outer of these ridges forms only an arcuate spur that extends downvalley from the east valley wall; however, the inner one forms a complete arc that crosses the valley 3.7 km upstream from the drift border.

Fresh, gravelly outwash can be traced downslope along numerous small, shallow stream valleys that drain from McDonald Ridge end moraines on the south flank of the volcano. Most of the deposits are concentrated close to stream channels, and underlie shallow terraces 1 to 2 m above modern streams. Bulky valley fills of outwash are lacking on this part of the mountain; apparently outwash was distributed widely along numerous small channels, rather than concentrated in a few large valleys. Furthermore, stream deposits may have been reduced by subsurface movement of meltwater through permeable lava.

Nature and weathering of till. Roadcuts in McDonald

Ridge end moraines expose fresh, gray till that appears distinctly more bouldery than White Salmon till (Fig. 52). Weathering of the till is slight and nearly all stones in the weathering profile are firm. Weathering rinds on stones are less than 0.5 mm thick, and rinds on many stones are incipient or absent. Striated surfaces, though well preserved on stones in the weathering profile, often are partially destroyed on surface boulders by extensive exfoliation (Fig. 53). However, because boulder surfaces show little decomposition, their destruction may be due to processes other than normal weathering; fire-spalling is a possibility.

Soil on McDonald Ridge till is weakly developed. Usually it consists of a very dark gray (10YR 3/3) A horizon, 10 to 20 cm thick, directly overlying oxidized, yellowish-brown (10YR 5/4) till that grades downward to fresh, gray till at a depth of 0.8 to 1.3 m. The oxidized horizon is friable, lacks obvious structure, and shows no detectable stickiness or plasticity. Thus, soil developed on McDonald Ridge till appears to lack a textural B horizon.

Big Muddy Creek Drift

Distribution and character. Moraines and outwash deposited during Neoglaciation (Porter and Denton, 1967) are referred to here as the Big Muddy Creek Drift. The drift is named for moraines in the upper Big Muddy Creek drainage that

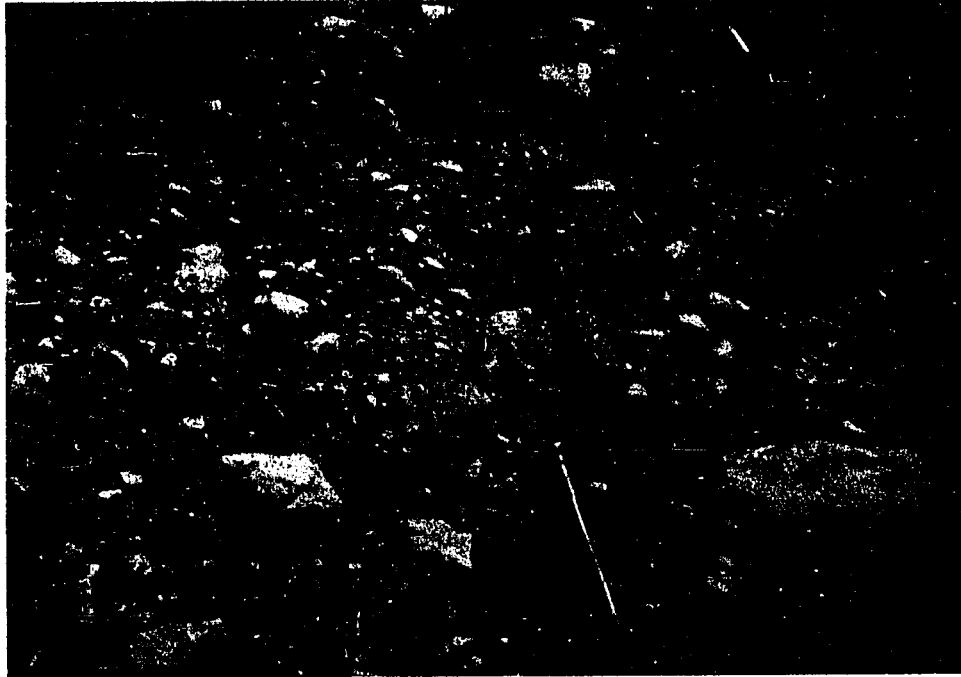


Figure 52. Relatively unweathered McDonald Ridge till exposed in end moraine in SW 1/4, Sec.11, T.7N., R.11E. Note fresh surfaces of most stones.

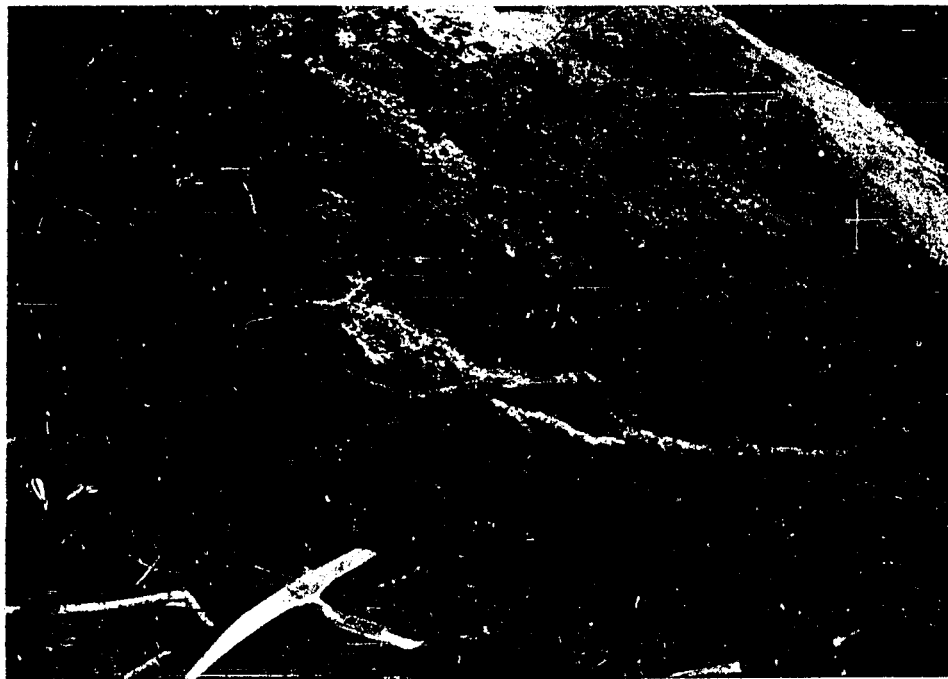


Figure 53. Surface boulder of andesite on McDonald Ridge end moraine at Snowplow Mountain. Fresh, abraded surface is partly destroyed by exfoliation, yet boulder shows little decomposition.

overlie pyroclastic layer δ . End moraines of the Big Muddy Creek Drift typically form prominent embankments of loose, blocky, unweathered rubble between 1950 and 2440 m (6400 and 8000 ft), a short distance beyond existing glaciers (Fig. 54). They are steep-sided, sharp-crested ridges that show little erosion. Moraines of Klickitat and Rusk glaciers, however, were deposited in deep valley heads and extend as low as 1520 m (5000 ft). These moraines range widely in size and form from sharp-crested lateral ridges 60 m high, to low, rounded, recessional arcs, just a few meters high, that lie on the valley floors. Unlike the higher moraines above timberline, most moraines of Klickitat and Rusk glaciers are vegetated and largely stabilized. They are composed of essentially unweathered till overlain on the outermost ridges by a thin layer of organic matter.

Age of Klickitat Glacier moraines. The most complete sequence of moraines within the Big Muddy Creek Drift occurs in front of Klickitat Glacier (Fig. 55). Trees growing on the moraines show progressive increase in size from small seedlings on the innermost ridges to trunks 60 to 80 cm in diameter on the outermost moraine. The largest trees, however, are smaller and appear younger than trees growing in the forest just beyond the moraines. The relationships indicate that trees growing on the Klickitat Glacier moraines comprise a first-generation forest; thus, the oldest trees are nearly



Figure 54. End moraines of Big Muddy Creek Drift at Mazama Glacier. End moraines are prominent, sharp-crested ridges at left-center and right.



Figure 55. Klickitat Glacier and moraines of Big Muddy Creek Drift.

as old as the moraines on which they grow.

Minimum ages were determined for the Klickitat Glacier moraines from ring counts on trees growing on the moraines (Lawrence, 1950). Ring counts were made on 65 trees, mostly from cores obtained with a Swedish increment borer. In some places, complete sections were cut from small trees on the youngest moraines. Initial counts were made in the field, and the oldest samples from each moraine were saved for later verification. The ring counts give minimum ages for the moraines because (1) the first trees to grow may not have been sampled, (2) the earliest growth rings are not recorded in cores taken above the base of a tree, and (3) an unknown amount of time separates withdrawal of the ice and the earliest germination of tree seeds (Lawrence, 1950, p. 245). Estimates of the time required for tree seeds to germinate can be made by sampling trees from sites whose dates of deglaciation are known (Sigafos and Hendricks, 1961, p. A11). Ring counts on trees growing at a site uncovered by Klickitat Glacier about 1890 (Rusk, 1924, p. 38), indicate that the germination period at Mount Adams is about 15 years. At Mount Rainier, this period averages about 5 years for valley-bottom sites having ample seed supply (Sigafos and Hendricks, 1961, p. A12; 1969, p. B92) but may be 50 years or more near timberline (Sigafos and Hendricks, 1972, p. B17). Inasmuch as errors arising from the sources listed above are difficult to evaluate, reported ages are the uncorrected ring counts

obtained; actual ages of the moraines may be a few decades greater.

Neoglacial moraines of Klickitat Glacier mark former positions of the ice front over the past five centuries (Fig. 56). The oldest moraines form sharply defined ridges, separated by swales 4 to 15 m deep, along the north side of the valley. The outermost of these moraines bears trees that began growing at least 461 years ago, indicating that the moraine was built during the late 15th or early 16th century. It is succeeded inward by a series of nearly parallel ridges built between the mid-16th and the late 18th centuries. The configuration of these moraines suggests that they were deposited by a glacier that was significantly broader than that which built the 19th- and 20th-century moraines.

At its maximum Neoglacial stand, measured along the valley axis, Klickitat Glacier terminated 2.7 km beyond its 1967 position. The end moraine formed at this time includes a prominent lateral moraine that rises 60 m above Big Muddy Creek on the north side of the valley (Figs. 57 and 58). The oldest trees growing on the end moraine are 124 years old, indicating that retreat from this position began before 1843. Low recessional moraines on the valley floor (Figs. 59 and 60) record a fluctuating retreat marked by four stillstands or minor readvances during the late 19th and early 20th centuries.

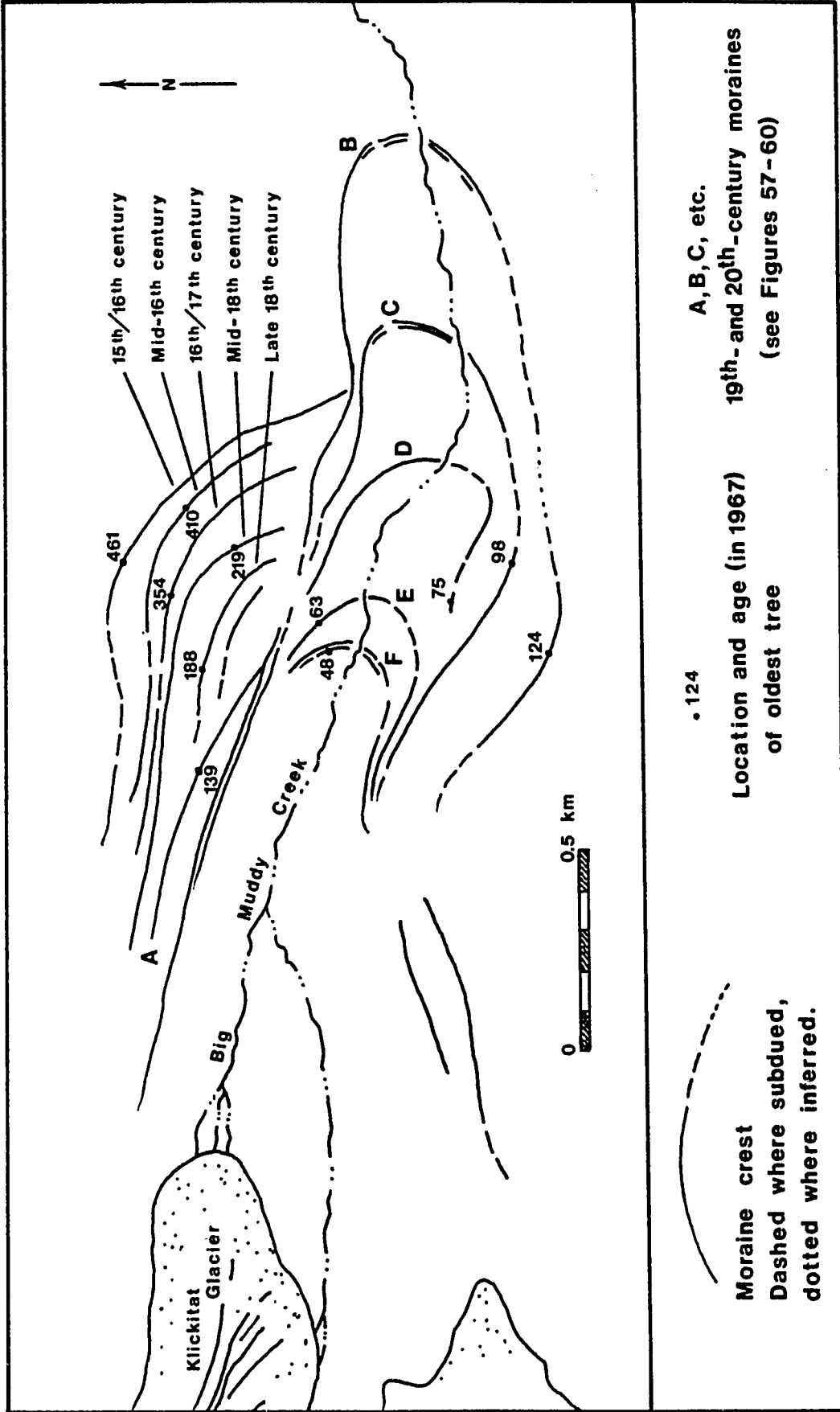


Figure 56. Neoglacial moraines of Klickitat Glacier

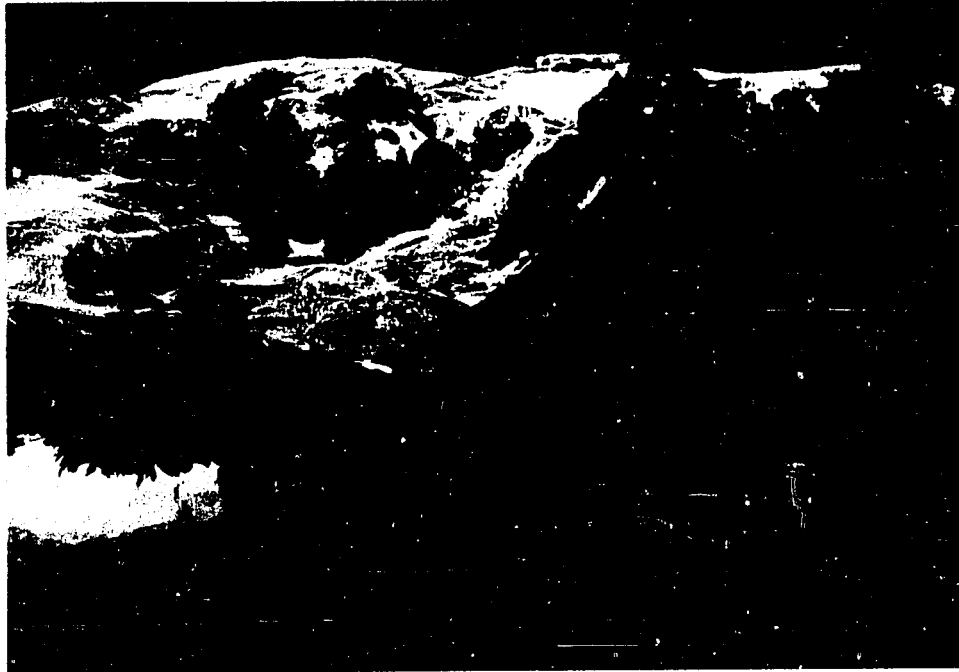


Figure 57. View west along compound lateral moraine north of Big Muddy Creek. Crest right of center is lateral ridge of end moraine B. Lower crest (center) probably is lateral ridge of end moraine C. Figure barely visible in swale between crests gives scale.

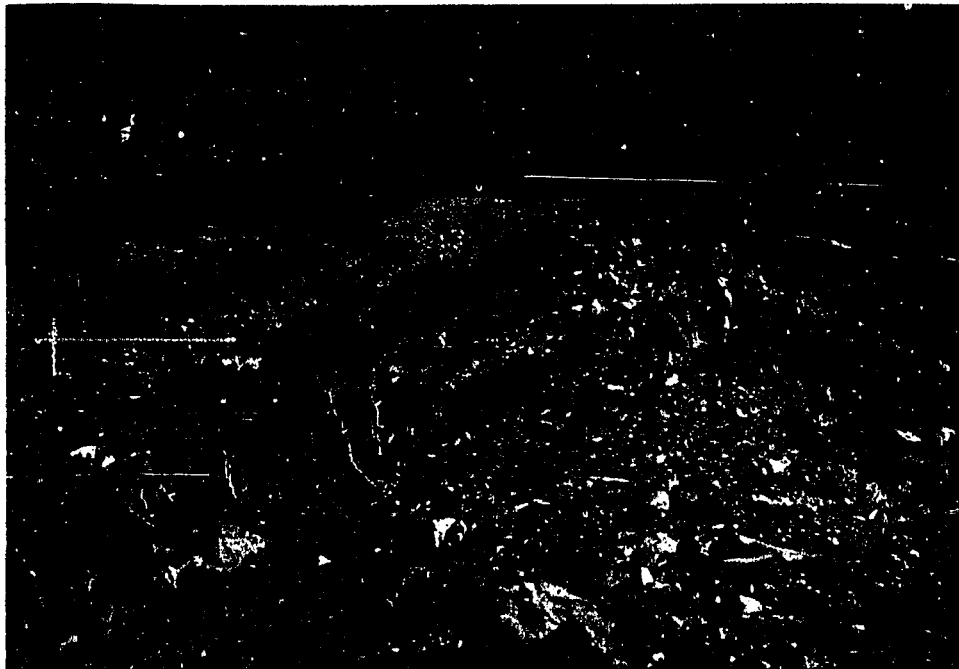


Figure 58. View east along lateral ridge of end moraine B. Lower crest on extreme right probably is lateral ridge of end moraine C. Prominent, light-colored ridge on left is moraine A.

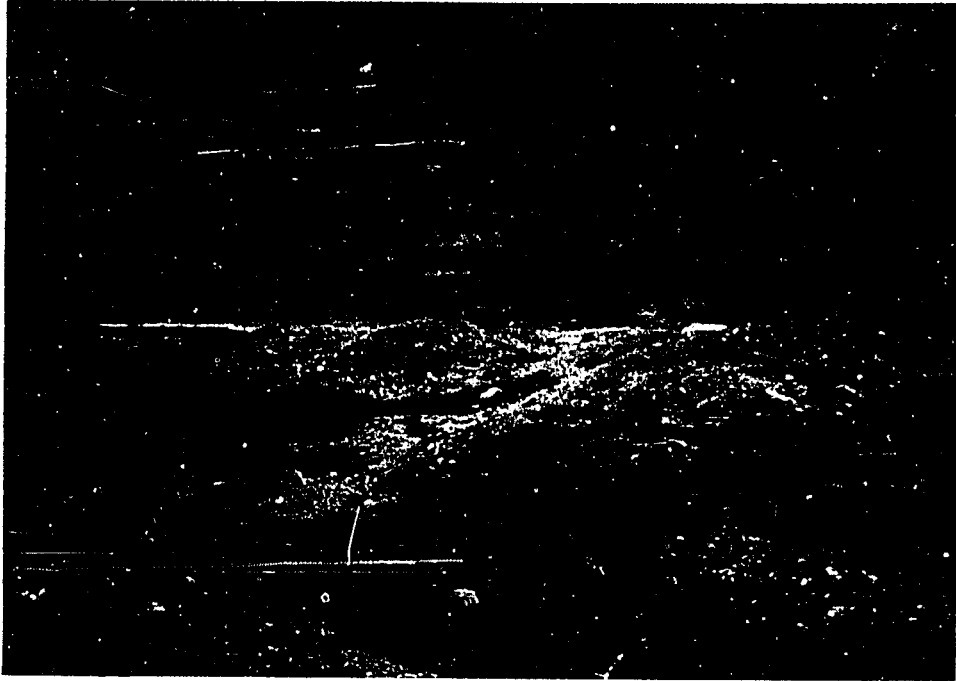


Figure 59. Terminal part of end moraine C forming hummocky, arcuate ridge on valley floor. Forest trimline on opposite valley side is traceable to terminal moraine B.

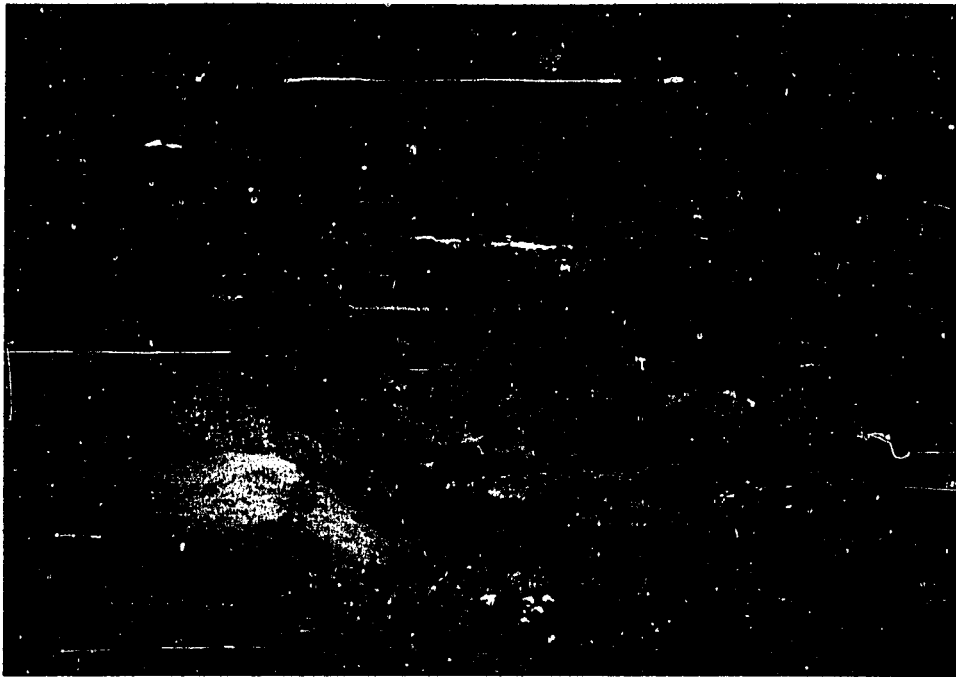


Figure 60. Double-crested terminal loop of moraine F. Figure on inner ridge gives scale. Small trees on inner ridge were as much as 48 years old in 1967.

The Klickitat Glacier moraines apparently postdate the two oldest of four tephra layers studied on the south flank of the volcano (see Fig. 45). Layers γ and δ are absent from the moraines, but occur in exposures 500 m east of the 15th/16th-century moraine. Layer ϕ , identified from field criteria, is present on the 15th/16th-century moraine where it is 0.5 to 1.0 cm thick at the base of the organic layer. Distinct ash layers were not found on younger moraines; however, small grains of an unidentified pumice are disseminated in the upper few centimeters of surficial cover on the late 18th-century moraine and on all older moraines.

Rusk Glacier moraines. Neoglacial moraines of Rusk Glacier form a somewhat different pattern than do those of Klickitat Glacier. The innermost moraine, which is largely unvegetated, is a bulky ridge of unstable material that lies 0.5 to 1.0 km beyond the glacier margin. The only other prominent end moraines in front of Rusk Glacier form sharp-crested lateral ridges along the south side of Rusk Creek and swing northward across the valley floor approximately 2.8 km downstream from the glacier terminus. The latter ridges are completely stabilized and heavily forested. A few cores taken from trees on the outermost ridge suggest that the moraine is at least as old as the outermost moraine of Klickitat Glacier; however, accurate ring counts could not be obtained because the trees which were sampled had rotten centers.

Correlation

Suggested correlations between the glacial sequence at Mount Adams and chronologies established for the Puget Lowland and Mount Rainier are shown in Table 3. Established chronologies, and the criteria upon which the correlations are based, are discussed below.

Pleistocene events. Four Pleistocene glaciations are recognized in western Washington (Crandell and others, 1958, Armstrong and others, 1965). The youngest, or Fraser Glaciation, began with the growth of alpine glaciers in the Cascades during the Evans Creek Stade. In the Puget Lowland, strata representing the Fraser Glaciation include drift deposited during the Vashon and Sumas stades. Vashon Drift was deposited by continental ice from the mountains of British Columbia; Sumas Drift represents a minor readvance of the Cordilleran glacier that was confined to the Fraser Lowland near the International Boundary. Stratigraphic relationships between the Evans Creek and Vashon drifts, along the western front of the Cascades, indicate that alpine glaciers had retreated significantly before Cordilleran ice reached its maximum extent (Cary and Carlston, 1937; Mackin, 1941; Crandell, 1963). At Mount Rainier, drifts deposited during the Fraser Glaciation are named Evans Creek and McNeeley; the latter is correlated with the Sumas Drift in the Fraser Lowland (Crandell and Miller, 1974).

<p>Puget Lowland (Crandell and others, 1958; Armstrong and others, 1963)</p>	<p>Mount Rainier (Crandell, 1969; Crandell and Miller, 1964, 1974)</p>	<p>Mount Adams (Hopkins, this study)</p>
	<p>Winthrop Creek Drift</p>	<p>Big Muddy Creek Drift</p>
	<p>Garda Drift</p>	<p>moraines of Klickitat Glacier</p>
<p>Fraser Drift</p>	<p>McNeeley Drift</p>	<p>McDonald Ridge Drift</p>
<p>Sumas Drift</p>	<p>Evans Creek Drift</p>	
<p>Salmon Springs Drift</p>	<p>Hayden Creek Drift</p>	<p>White Salmon Drift</p>
<p>Salmon Springs Drift (?)</p>	<p>Wingate Hill Drift</p>	

Table 3. Proposed correlations of the glacial sequence at Mount Adams with chronologies for the Puget Lowland and Mount Rainier.

The previous, or Salmon Springs, glaciation is represented in the Puget Lowland by drift deposited during two separate stades of ice-sheet glaciation. At Mount Rainier, drift representing at least the latter part of Salmon Springs time is named Hayden Creek (Crandell, 1969; Crandell and Miller, 1974). An older drift at Mount Rainier, the Wingate Hill, may represent early Salmon Springs time; however, correlation is uncertain (Crandell and Miller, 1974, p. 55).

The McDonald Ridge Drift at Mount Adams is considered essentially Fraser in age. Inasmuch as the Evans Creek Stade is defined as the maximum alpine advance of the Fraser Glaciation (Armstrong and others, 1965, p. 326), the McDonald Ridge Drift may be largely of Evans Creek age. Evans Creek Drift at Mount Rainier is oxidized to a maximum depth of 1.2 m, and stones in the weathering profile generally lack discernible rinds (Crandell and Miller, 1974, p. 29); thus, weathering of the Evans Creek Drift compares closely with that of the McDonald Ridge Drift at Mount Adams. Although McDonald Ridge Drift may include deposits of multiple stades, it has not been subdivided; thus, it is equated broadly with the Evans Creek and McNeeley drifts at Mount Rainier.

The White Salmon Drift of the study area tentatively is considered to be of Salmon Springs age, and is correlated with the Hayden Creek Drift at Mount Rainier. Till of probable Salmon Springs age in the Cascade Range typically is oxidized

to depths of 2 to 4 m (Crandell, 1965, 346). Hayden Creek till at Mount Rainier is oxidized to a depth of about 2 m, and stones in the weathering profile have rinds 0.5 to 2.5 mm thick (Crandell and Miller, 1974, p. 21). Similar weathering is typical also of the White Salmon Drift at Mount Adams.

Neoglacial events. Neoglacial deposits at Mount Rainier have been assigned to the Winthrop Creek Glaciation (Crandell and Miller, 1964). Drift of Winthrop Creek age was deposited during two stades, separated by at least 1000 years. Burroughs Mountain Drift, deposited during the earlier stade, can be recognized because it is older than tephra layer C, and younger than tephra layer Y (Crandell, 1969, p. 28). Layer C, which was erupted from Mount Rainier, is approximately 2200 years old, whereas the most prominent member of set-Y tephra at Mount Rainier (layer Yn of Mullineaux, 1974) is approximately 3400 years old (Mullineaux, 1974, p. 25). The Garda Drift, deposited during the later stade, postdates tephra layer C, and includes moraines bearing trees at least 750 years old (Crandell, 1969, p. 30). Locally it is subdivided into drift older than tephra layer W from Mount St. Helens (450 years old), and drift younger than layer W.

The Big Muddy Creek Drift is broadly equivalent to drift of the Winthrop Creek Glaciation at Mount Rainier. Broad correlation of the two drifts is based on similarities in altitude, freshness, and position with respect to existing

glaciers. Furthermore, Big Muddy Creek Drift apparently postdates tephra-layer δ , which tentatively is correlated with tephra-set Y. On the basis of tree-ring data, Neoglacial moraines of Klickitat Glacier are assigned to the Garda Stade.

The chronology of Klickitat Glacier Neoglacial moraines is broadly similar to that of Garda moraines at Mount Rainier. Most Garda moraines at Mount Rainier were built between mid-14th and mid-19th centuries (Crandell and Miller, 1964, p. D113); however, they do not form a consistent pattern between glaciers. End moraines marking the maximum stand of at least eight Mount Rainier glaciers date from the mid-19th century (Sigafos and Hendricks, 1972), and they therefore compare closely in age to the moraine built during the maximum advance of Klickitat Glacier.

Trout Lake Mudflow

A diamicton that underlies approximately 16 km^2 of the valley floor along the White Salmon River near Trout Lake is here named the Trout Lake Mudflow (Fig. 61). The diamicton is recognized as a mudflow primarily on the basis of internal characteristics and morphology; however, the distribution and age of the deposit clearly preclude a glacial origin.

Internal characteristics

The mudflow is best exposed in streambanks along the

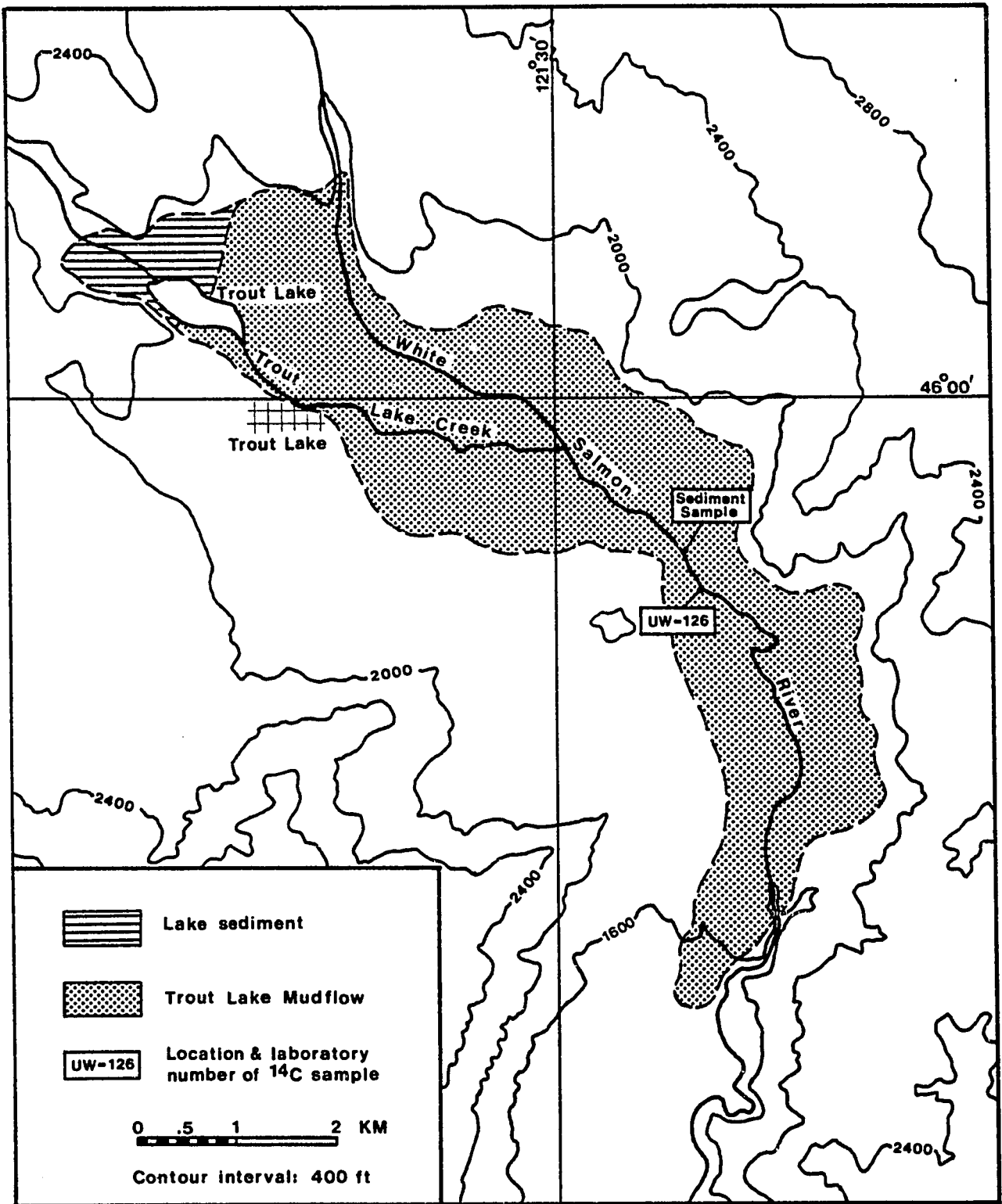


Figure 61. Distribution of the Trout Lake Mudflow near Trout Lake.

White Salmon River. The sediment is a mixture of coarse, subangular to subrounded stones in a brownish-gray, plastic matrix of sand, silt, and clay (Fig. 62). Boulders as much as 2 m in diameter occur in the deposit, but most stones have diameters less than 60 cm. Although the sediment lacks obvious sorting, the uppermost meter of most sections shows a marked decrease in the size of stones; large cobbles and boulders in this zone are rare. Vertical-size gradation of this kind has been widely noted in mudflow and debris-flow sediments at Mount Rainier, and seems to be a common characteristic of such deposits (Crandell, 1971, p. 6).

Mechanical analysis of a sediment sample, collected approximately 2 m below the mudflow surface from a stream-bank exposure (Fig. 61), yielded the following particle-size distribution:

Size Fraction (USDA Classification)		Weight Percent of Sample
Gravel	>2.00 mm	43
Sand	2.00-0.05 mm	36
Silt	0.05-0.02 mm	15
Clay	<0.002 mm	6

The data may not be representative of the entire deposit because stones larger than 70 mm were not included in the sample. However, more than 50 percent of the analyzed sample consists of particles of sand size or smaller; therefore, the sediment fits the definition given by Varnes (1958, p. 37) to distinguish mudflows from other mass-flowage deposits.

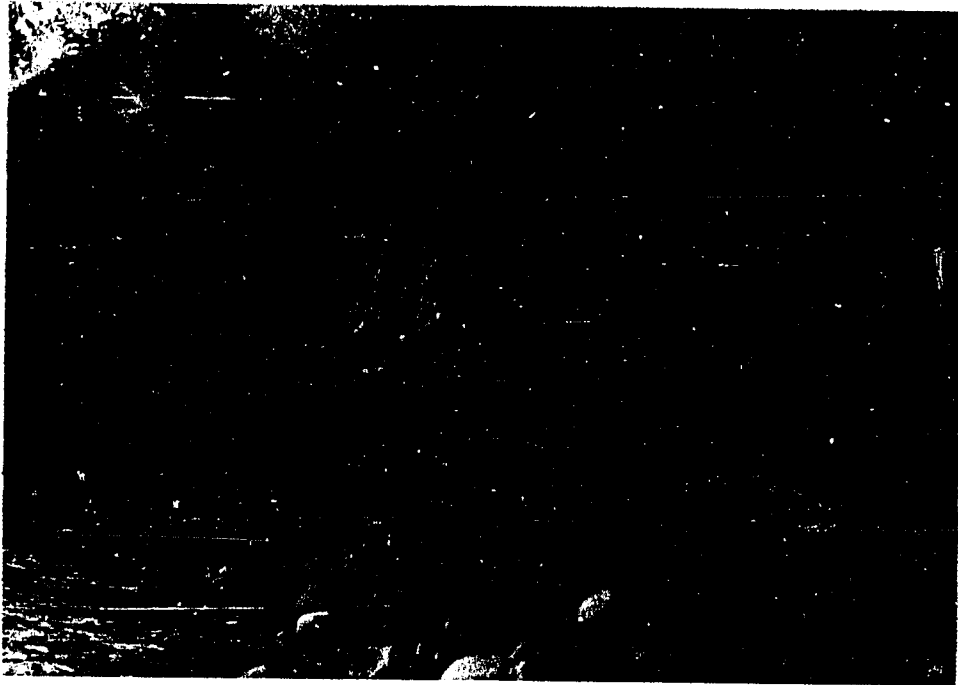


Figure 62. Trout Lake Mudflow exposed in streambank along White Salmon River.



Figure 63. Flat surface of the Trout Lake Mudflow. Large boulders near center of photograph are solfatarized andesite derived from Mount Adams (background).

Pebble counts from two localities show that stones in the mudflow are 73 percent Mount Adams Volcanics, 21 percent County Park Olivine Basalt, and 6 percent dark volcanic rocks of unknown origin. Rocks derived from Mount Adams include gray, massive andesite; black, vesicular to scoriaceous andesite; and reddish-brown breccia. Many of the Mount Adams stones are strongly solfatarized, and some show hydrothermal alteration.

Wood fragments occur throughout the deposit. Fragments ranging from small chips to limbs 10 cm in diameter occur in streambank exposures along the White Salmon River; however, local farmers report finding whole tree trunks buried horizontally within the deposit.

Distribution, morphology, and thickness

The Trout Lake Mudflow forms a continuous cover on the floor of the White Salmon River valley, between 475 and 600 m (1560 and 2000 ft). The deposit is confined largely to the east half of the valley where it forms a lobe 8 km long and up to 3 km wide. The mudflow can be traced north to where it emerged from the relatively narrow valley of the upper White Salmon River. Near its northern end, the mudflow lobe disrupted the drainage of Trout Lake Creek forming Trout Lake. Lake sediments flooring the valley in that area indicate that the original lake was several times larger than the present Trout Lake.

The surface of the mudflow is exceedingly flat, and is broken only by occasional large boulders, or clusters of boulders, that project above it (Fig. 63). Along the eastern edge of the mudflow, this surface terminates abruptly against the steep valley side; to the west, the mudflow surface grades imperceptibly onto valley-filling olivine-basalt flows of the White Salmon valley.

The maximum thickness of the mudflow is unknown. The base of the mudflow can be seen only in a few exposures near its terminus along the White Salmon River (Sec. 31, T.6N., R.10E. and Sec. 6, T.5N., R.10E.), where the deposit is less than 1.5 m thick. The mudflow thickens northward, and nearly 3 m of mudflow sediment is exposed in streambanks in NW 1/4, Sec. 30, T.6N., R.10E.; however, in all of these exposures, the base of the mudflow lies below river level.

Source

The Trout Lake Mudflow probably originated high on the west side of Mount Adams. Although the mudflow has not been traced to its source, its distribution on the valley floor near Trout Lake indicates that it originated in the drainage basin of the upper White Salmon River. A source on Mount Adams is indicated by the abundant clasts of Mount Adams Volcanics. Strongly solfatarized and hydrothermally altered rock, like that commonly seen in the mudflow, crops out above White Salmon Glacier, near the volcano's summit. Crandell

(1971, p. 17) believes that altered rock of this kind not only is especially susceptible to failure and sliding, but probably is the principal source of the clay component in volcanic mudflows.

Age

A radiocarbon age of 5070 ± 260 years B.P. (UW-126) was obtained on wood from a tree stump collected near the base of the mudflow in a 2.5 m streambank exposure (Fig. 61). The reported date is based on a ^{14}C half life of 5568 years, and is not corrected for past variations in atmospheric ^{14}C (the calendar age is $5680 +270/-310$ years B.P.).

SUMMARY AND COMPARISON WITH NEARBY VOLCANOES

The Pacific Northwest volcanoes have been the subject of intensified geologic study in recent years so as to better understand the hazards they pose to nearby communities and recreational facilities. Two volcanic peaks in southern Washington, Mount Rainier and Mount St. Helens, have received special attention, whereas Mount Adams has remained relatively unknown. The data from Mount Adams presented here, although based on an examination of about half of the volcano, now permits some comparisons to be drawn between Mount Adams and the two neighboring volcanoes (Table 4).

Lava has been the principal product erupted from Mount Adams throughout its history. Lava flows comprise at least 75 percent of the volcano and most of the interflow breccias may consist of shattered lava. This compares closely to Mount Rainier where Fiske and others (1963, p. 75) estimated that products of volcanic explosion make up only an insignificant part of the cone. Volcanic activity at Mount St. Helens, however, has been predominately explosive. Hyde (1973, p. 95) estimated that tephra and flowage deposits comprise at least 85 percent of the material erupted from Mount St. Helens.

Mount Adams and Mount Rainier appear to be of similar age. The Klickitat River intracanyon flow, which probably was among the earliest flows erupted from Mount Adams, is

	Mount Rainier	Mount Adams	Mount St. Helens
Type of volcanic activity	Predominately effusive. Flows and brecciated lava comprise nearly all of material erupted.	Predominately effusive. Flows comprise >75% of material erupted. Most breccias probably are shattered lava.	Predominately explosive. Tephra, pyroclastic flows, and lahars comprise >85% of material erupted.
Earliest dated events	Lava flow ~320,000 to ~600,000 yrs. B.P.	Lava flow ~400,000 yrs. B.P.	Tephra ~37,600 yrs. B.P. Lahar ~36,000 yrs. B.P.
Earliest known glaciation of volcano	Early Salmon Springs (?) Represented by Wingate Hill Drift estimated to be slightly greater than 125,000 years old.	Salmon Springs Represented by White Salmon Drift which is correlated with Hayden Creek Drift (~40,000 - 80,000 years old) at Rainier. Some White Salmon Drift may be of Wingate Hill age.	Fraser Culminated ~18,000 years ago.
Holocene activity	Numerous lahars and several tephra layers of local extent. Lava eruptions minor and restricted to summit cone.	Lava flows up to 6.5 km. long from flank eruptions. Construction of parasitic tephra cones. Only one large lahar so far recognized. Pumiceous tephra not identified.	Prolific producer of wide-spread tephra deposits, pyroclastic flows, and lahars almost to present. Lava flows minor.

Table 4. Comparison of Mount Adams with Mount Rainier and Mount St. Helens. Data for Mount Rainier from Fiske and others (1963), Crandell (1971), Crandell and Miller (1974), Mullineaux (1974). Data for Mount St. Helens from Hyde (1973).

approximately 400,000 years old. Potassium-argon determinations on one of the early Mount Rainier flows have yielded ages of approximately 320,000 years and 600,000 years (Crandell and Miller, 1974, p. 17). Initial eruptions at both volcanoes apparently occurred much earlier than the first activity at Mount St. Helens. Hyde (1973) reported that the oldest dated volcanic products at Mount St. Helens are a tephra layer about 37,600 years old and a lahar about 36,000 years old.

Mount Adams had reached a height sufficient to accumulate large glaciers by White Salmon time. Correlation of the White Salmon Drift with the Hayden Creek Drift at Mount Rainier, which Crandell and Miller (1974, p. 56) believe was deposited between 40,000 and 80,000 years ago, implies that a large cone existed at Mount Adams at least 80,000 years ago. It is possible that some drift at Mount Adams mapped as White Salmon may prove to be equivalent to Wingate Hill Drift at Mount Rainier. If so, large glaciers may have existed at Mount Adams just before 125,000 years ago, the estimated age of the Wingate Hill Drift (Crandell and Miller, 1974, p. 56). In contrast, pre-Fraser (Hayden Creek age and older) drifts near Mount St. Helens apparently antedate the volcano (Hyde, 1973). Although drift apparently of pre-Wingate Hill age occurs beneath the earliest flows of Mount Rainier (Crandell and Miller, 1974), drift older than White Salmon has not been recognized at Mount Adams.

Unlike Mount St. Helens, where the present cone may be less than 2000 years old (Mullineaux and Crandell, 1962), the cones of Mount Adams and Mount Rainier have not grown significantly for at least several tens of millennia. Cone building at Mount Rainier was largely completed before the last glaciation (Fiske and others, 1963, p. 82), and large lava flows younger than the Hayden Creek Drift are unknown. However, at Mount Adams large lava flows from flank eruptions on Suksdorf Ridge overlie White Salmon (= Hayden Creek) Drift and, therefore, are considerably younger than the youngest flows of comparable size at Mount Rainier.

During Holocene time at Mount Rainier, numerous lahars, many of which were triggered by volcanic explosions, swept down valleys on the volcano's flanks (Crandell, 1971), and eruption of tephra occurred at least eleven times (Mullineaux, 1974). Lava eruptions were limited to relatively small flows that form the summit cone (Fiske and others, 1963). Holocene activity at Mount Adams, however, was marked by flank eruptions of lava flows as much as 6.5 km in length, and by construction of parasitic tephra cones. Within the study area, only a single large lahar has been recognized, and pumiceous tephra from Mount Adams has not been identified. Thus, it is perhaps in their later histories that Mount Adams and Mount Rainier contrast most strongly.

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VITA

Name: Kenneth Donald Hopkins

Born: Minneapolis, Minnesota, March 1, 1939

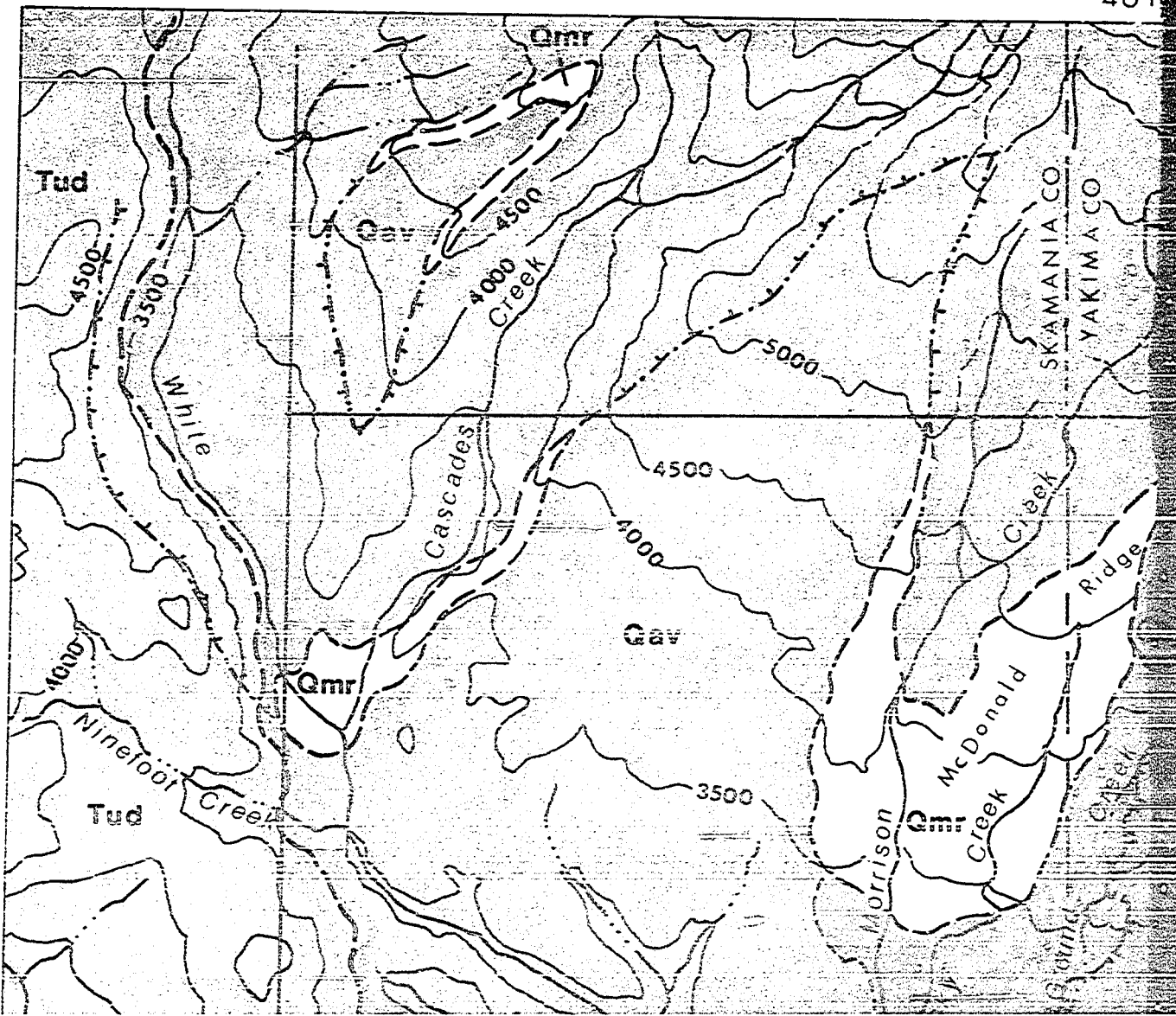
Parents: Mr. and Mrs. Frank L. Hopkins

Family: Wife Audrey, children Teresa and Christopher

Education: Washburn High School, Minneapolis, 1954-1957
University of Minnesota, 1957-1959, 1960-1963,
B.A.
University of Washington, 1963-1966, M.S.
University of Washington, 1967-1969, 1975-1976,
Ph.D.

R. 10 E.

461

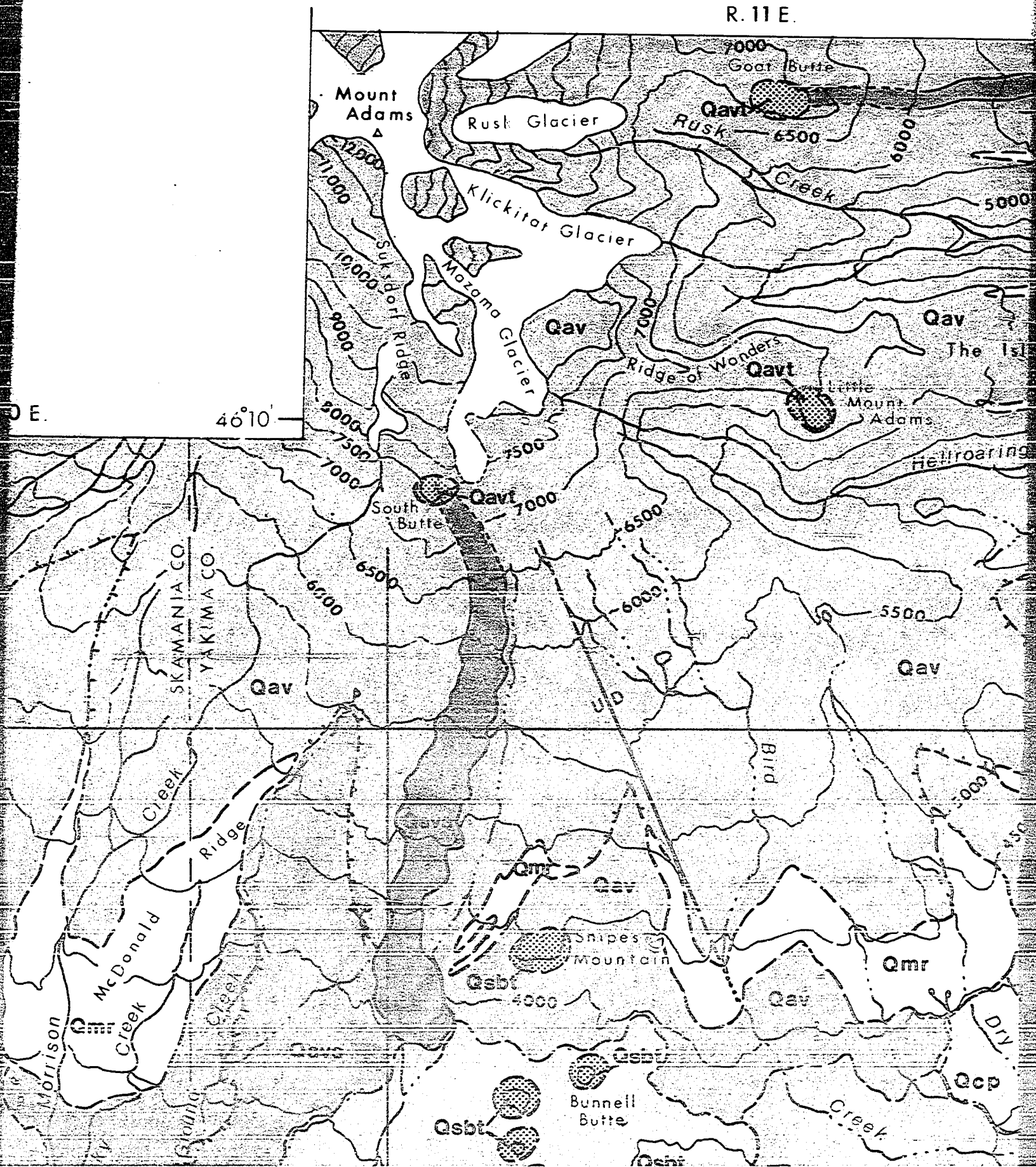


121°30'

R. 11 E.

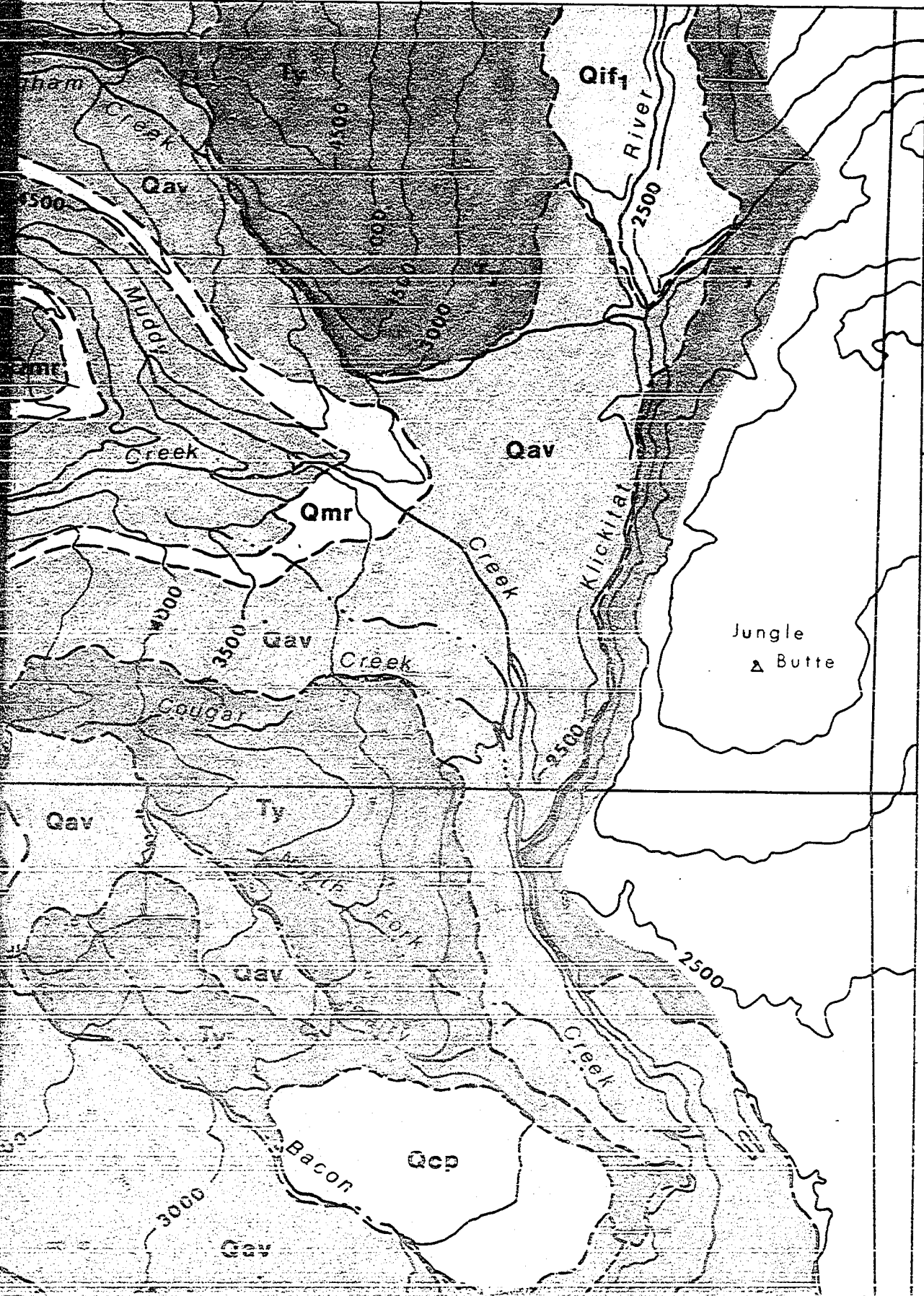
E.

46°10'



121°20'

R.12 E.



Holocene

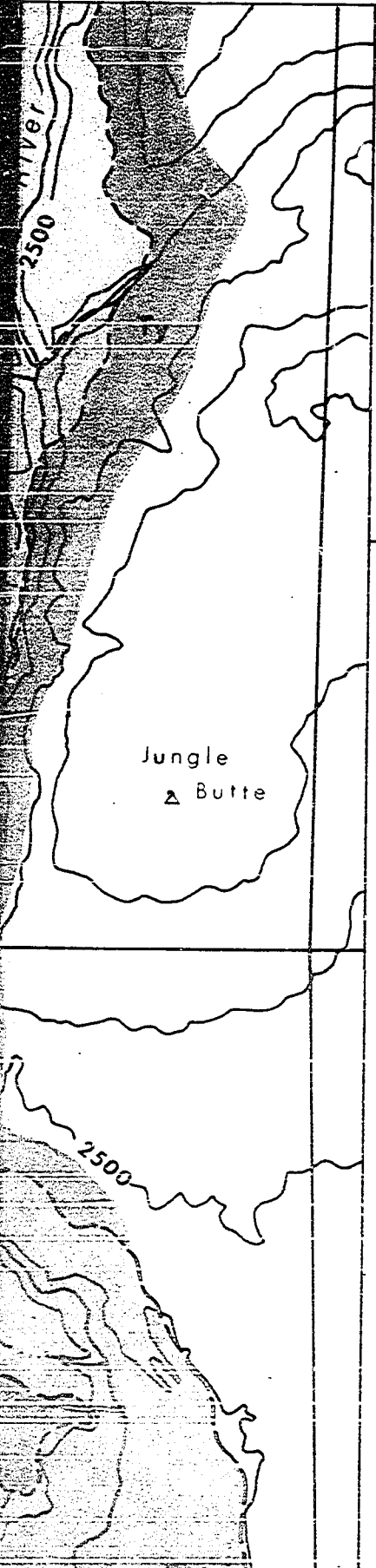
T.8 N.

46°10'

Pleistocene

T.7 N.

EXPLA



Holocene

Qava, andesite of the A.G. Aiken Lava Bed
 Qavc, andesite of the Cunningham Creek flow

Pleistocene

Andesite flows of Suksdorf Ridge

King Mountain
 Qkm, fl
 Qkmt, te



T. 8 N.
 46° 10'

T. 7 N.

Jungle
 ▲ Butte

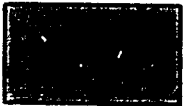
Mount Ada
 Qav, undiffe
 mostly an
 breccia
 Qavt, tephra

King Mountain
 Qkm, fl
 Qkmt, te

EXPLANATION



lava, andesite of the
A.G. Aiken Lava Bed
andesite of the
Cunningham Creek flow



andesite flows of Suksdorf
Ridge



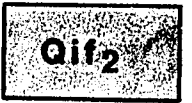
Mount Adams Volcanics
Qav, undifferentiated flows,
mostly andesite; minor
breccia
Qavt, tephra cones



King Mountain Olivine Basalt
Qkm, flows
Qkmt, tephra cones



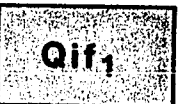
McDonald Ridge
Till forming prominent
moraines



Intracanyon olivine
flows of the White
River




Smith Butte Olivine
Qsb, flows
Qsbt, tephra cones

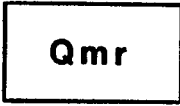


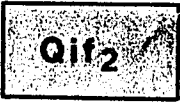
Intracanyon olivine
flows of the Klicki

EXPLANATION

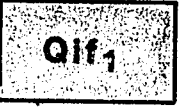

 Mount Adams Volcanics
 Qav, undifferentiated flows,
 mostly andesite; minor
 breccia
 Qavt, tephra cones


 King Mountain Olivine Basalt
 Qkm, flows
 Qkmt, tephra cones


 McDonald Ridge Drift
 Till forming prominent end
 moraines



 Intracanyon olivine basalt
 flows of the White Salmon
 River



 Smith Butte Olivine Basalt
 Qsb, flows
 Qsbt, tephra cones

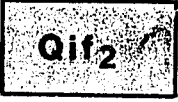

 Intracanyon olivine basalt
 flows of the Klickitat River


QUATERNARY


EXPLANATION


- 

McDonald Ridge Drift
Till forming prominent end moraines
- 

Mount Adams Volcanics
Qav, undifferentiated flows,
mostly andesite; minor
breccia
Qavt, tephra cones
- 

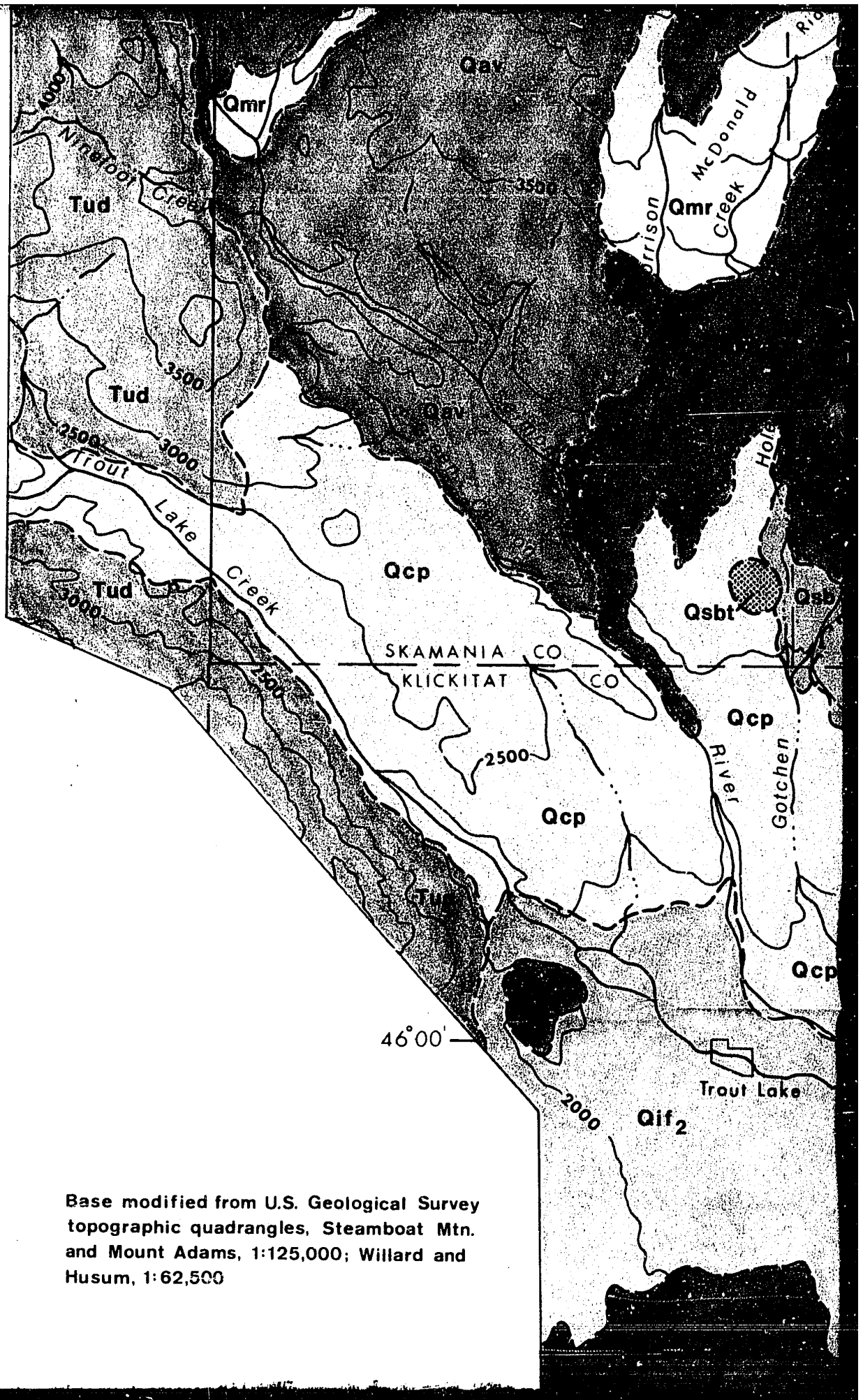
Intracanyon olivine basalt
flows of the White Salmon
River
- 

Smith Butte Olivine Basalt
Qsb, flows
Qsbt, tephra cones
- 

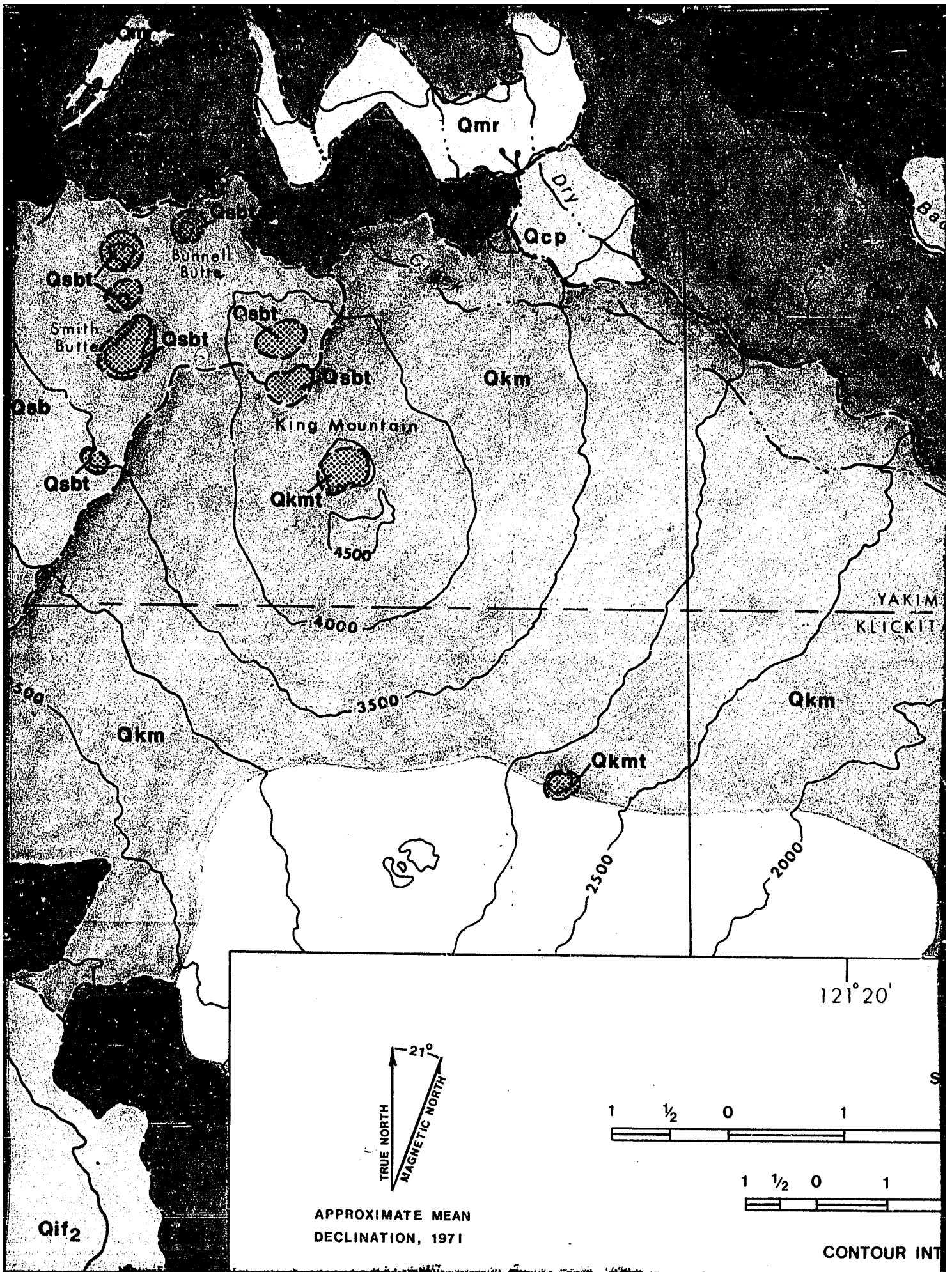
Intracanyon olivine basalt
flows of the Klickitat River
- 

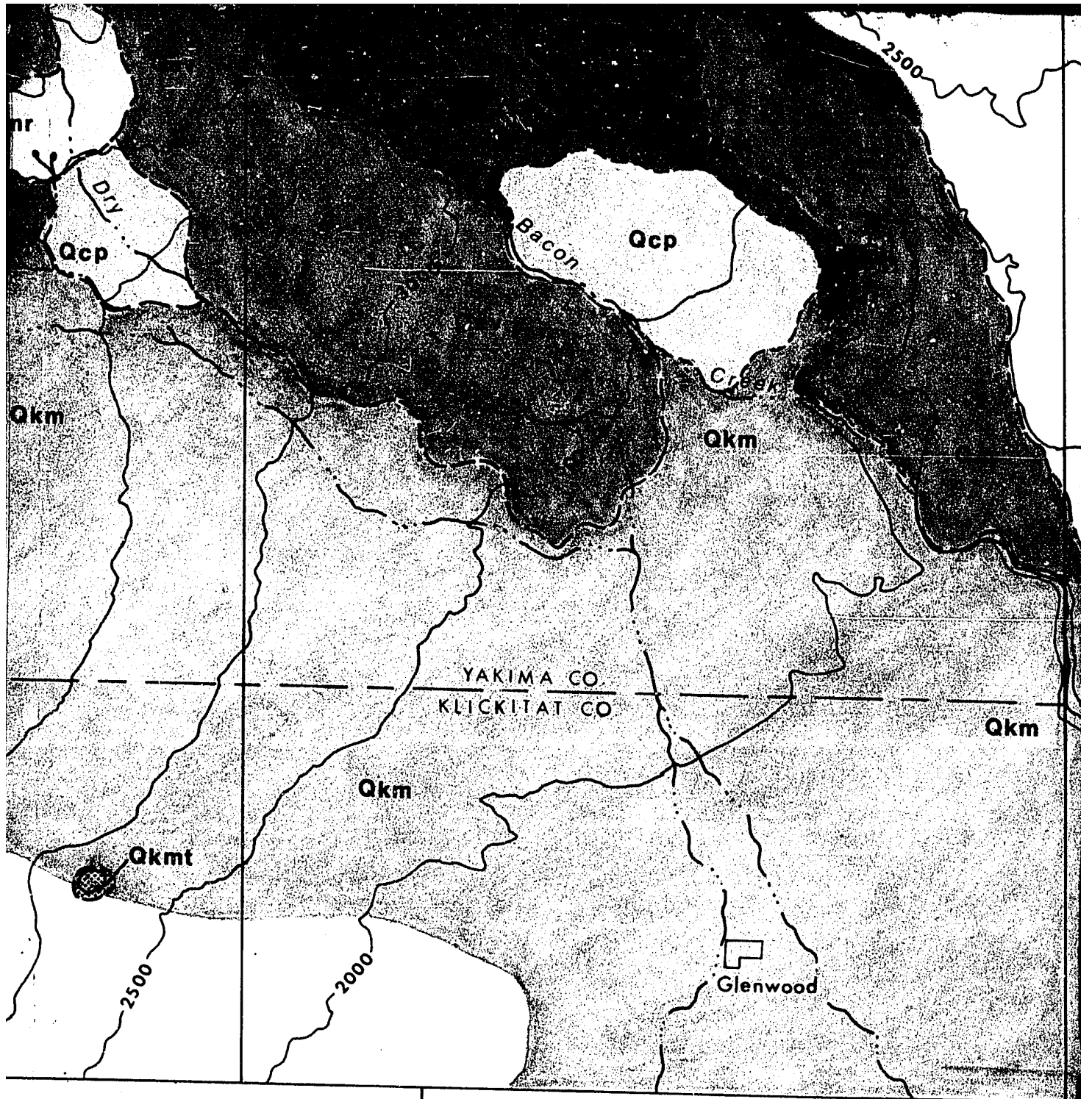
King Mountain Olivine Basalt
Qkm, flows
Qkmt, tephra cones

QUATERNARY



Base modified from U.S. Geological Survey topographic quadrangles, Steamboat Mtn. and Mount Adams, 1:125,000; Willard and Husum, 1:62,500

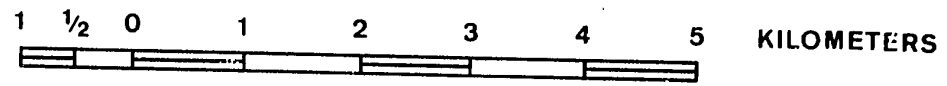
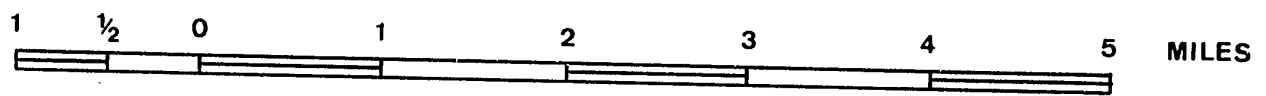




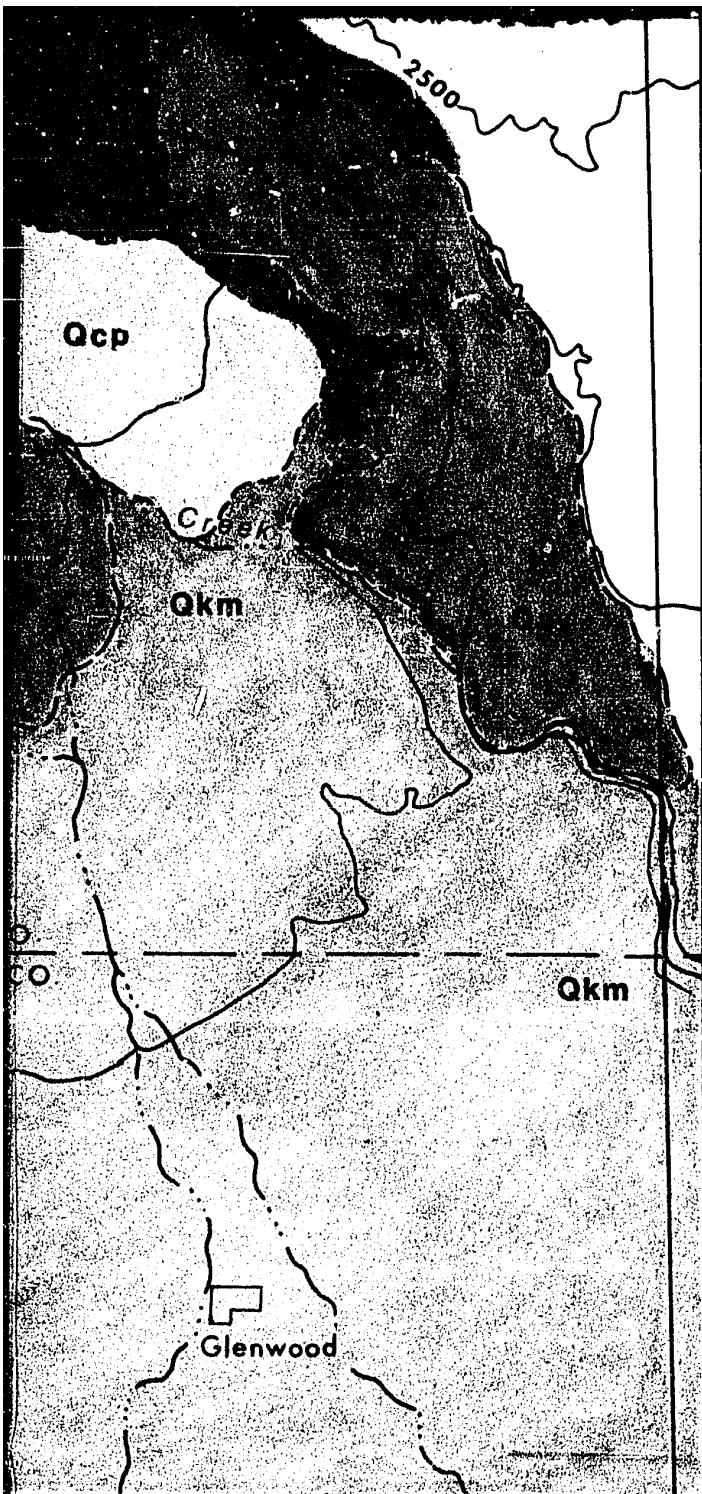
121°20'

Geology mapped in 1967-68

SCALE



CONTOUR INTERVAL 500 FEET



T.7 N.

T.6 N.

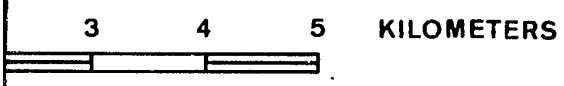
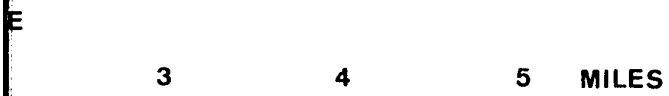
46°00'

Geology mapped in 1967-69

Pliocene or
Pleistocene

Miocene or
Pliocene

Eocene or
Oligocene



AL 500 FEET

Contact
Dashed where approximate
short dashed where in

Fault
Dashed where approximate
dotted where concealed
side; D, downthrown side

Intrac
flow

Z.

Pliocene or
Pleistocene

Miocene or
Pliocene

Eocene or
Oligocene

Z.

6°00'



King Mountain Olivine Basalt
Qkm, flows
Qkmt, tephra cones



County Park Olivine Basalt
Qcp, flows
Qcpt, tephra cones

UNCONFORMITY



Yakima Basalt



Undifferentiated volcanoclastic
rocks and lava flows

Contact
Dashed where approximately located,
short dashed where inferred

Approximate m
where not ma
moraines, du
Dots included

U
D

Fault
Dashed where approximately located,
dotted where concealed. U, upthrown
side; D, downthrown side

Flow overlaps o
rock unit. H
younger flow

Qlf₁

Intracanyon olivine basalt flows of the Klickitat River

Qkm

King Mountain Olivine Basalt
Qkm, flows
Qkmt, tephra cones

Qcpt
Qcp

County Park Olivine Basalt
Qcp, flows
Qcpt, tephra cones

UNCONFORMITY

Yakima Basalt

Yakima Basalt

Undifferentiated volcaniclastic rocks and lava flows

Undifferentiated volcaniclastic rocks and lava flows

TERTIARY OR QUATERNARY

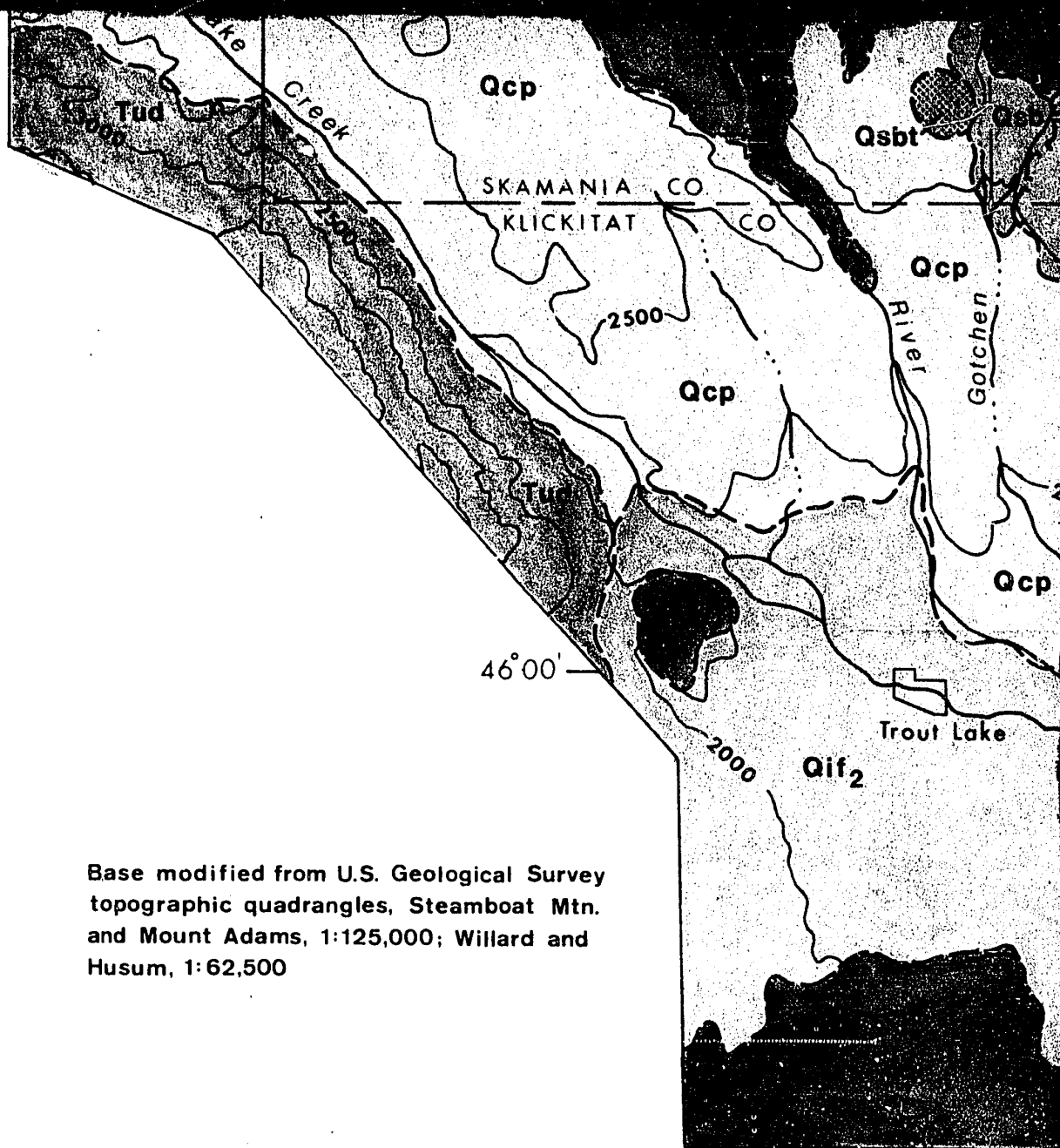
TERTIARY

located,
red

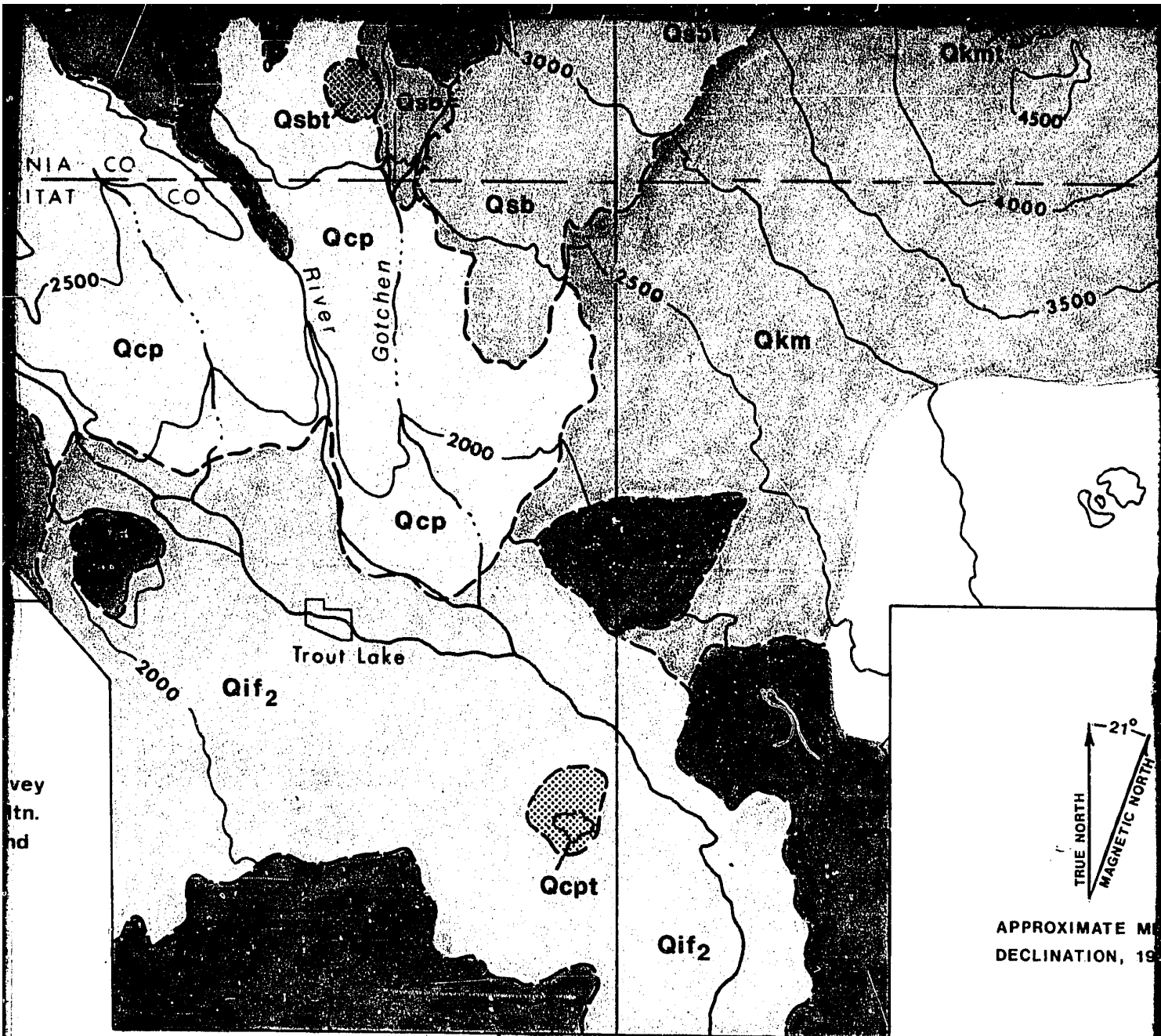
Approximate maximum extent of glaciation, where not marked by prominent end moraines, during McDonald Ridge time. Dots included where inferred

.....
located,
U, upthrown

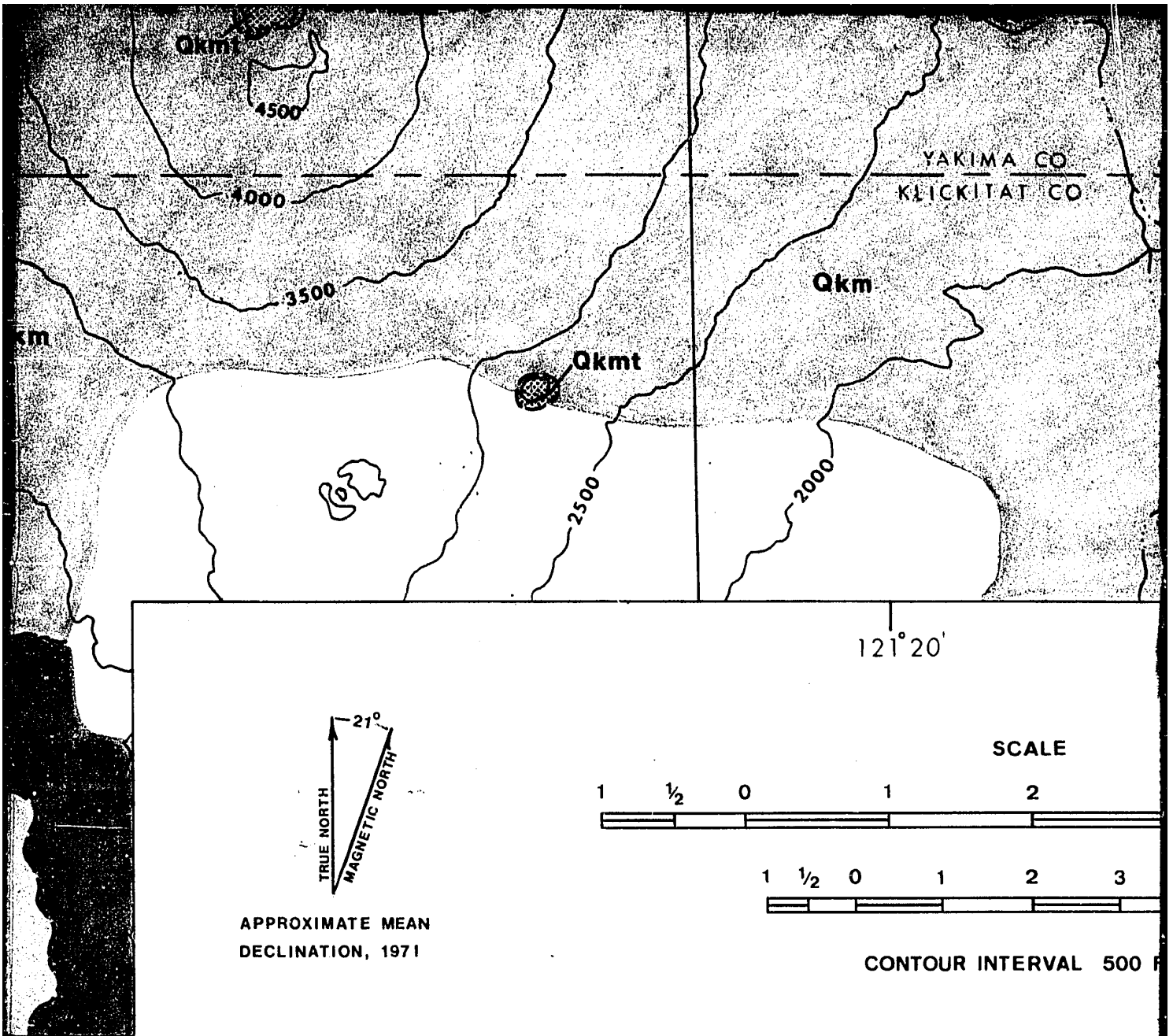
Flow margin
Flow overlaps older flows of same rock unit. Hachures drawn on younger flow. Not mapped inside



Base modified from U.S. Geological Survey
topographic quadrangles, Steamboat Mtn.
and Mount Adams, 1:125,000; Willard and
Husum, 1:62,500

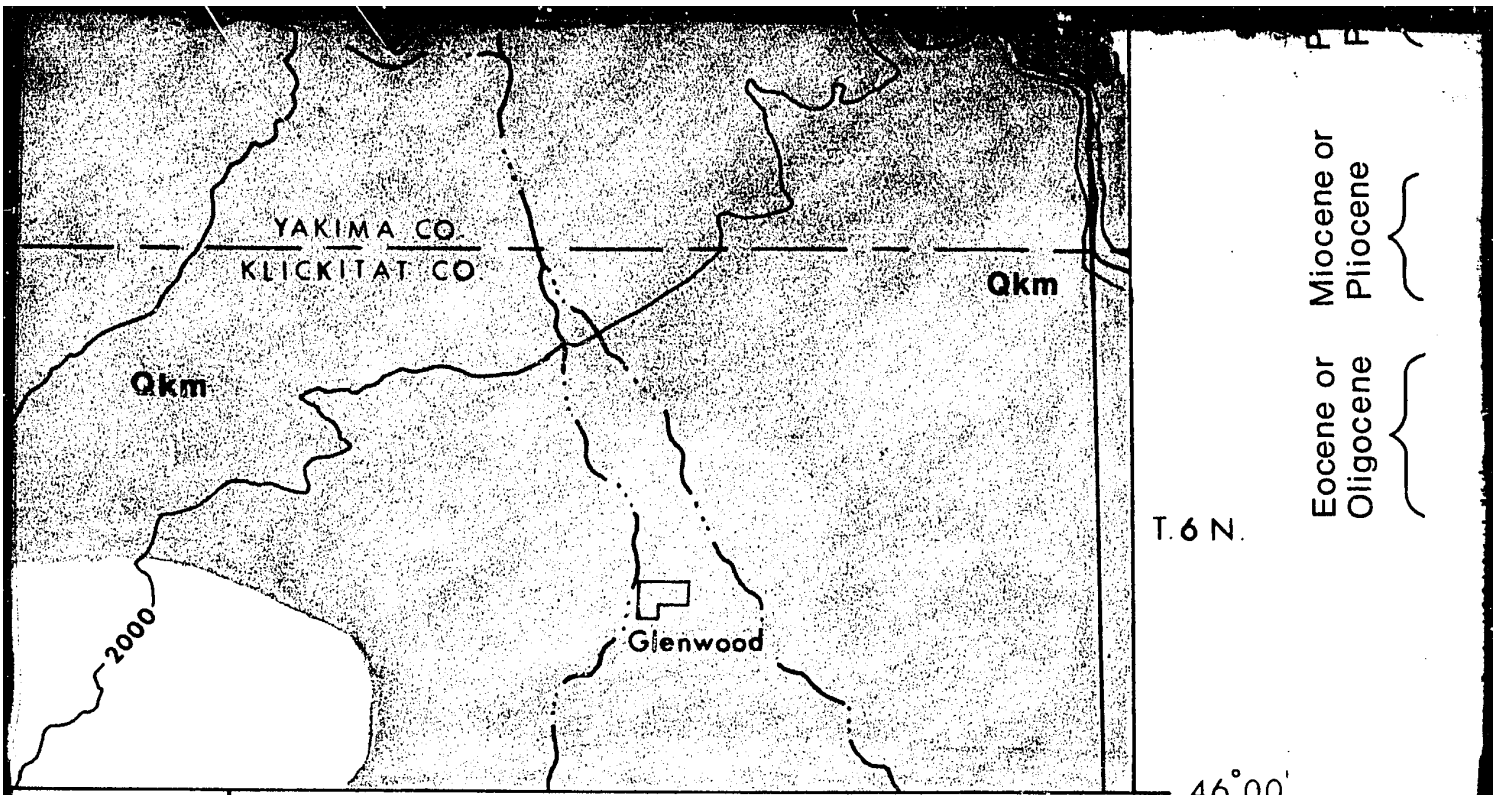


GEOLOGIC MAP OF THE S



MAP OF THE SOUTH AND EAST SLOPES OF

By
Kenneth D. Hopkins
 1976

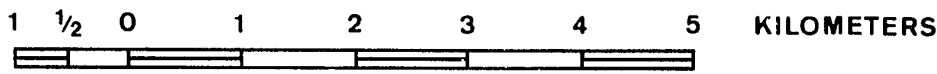
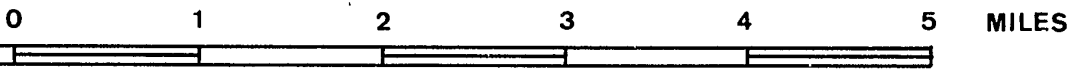


Geology mapped in 1967-69

121° 20'

46° 00'

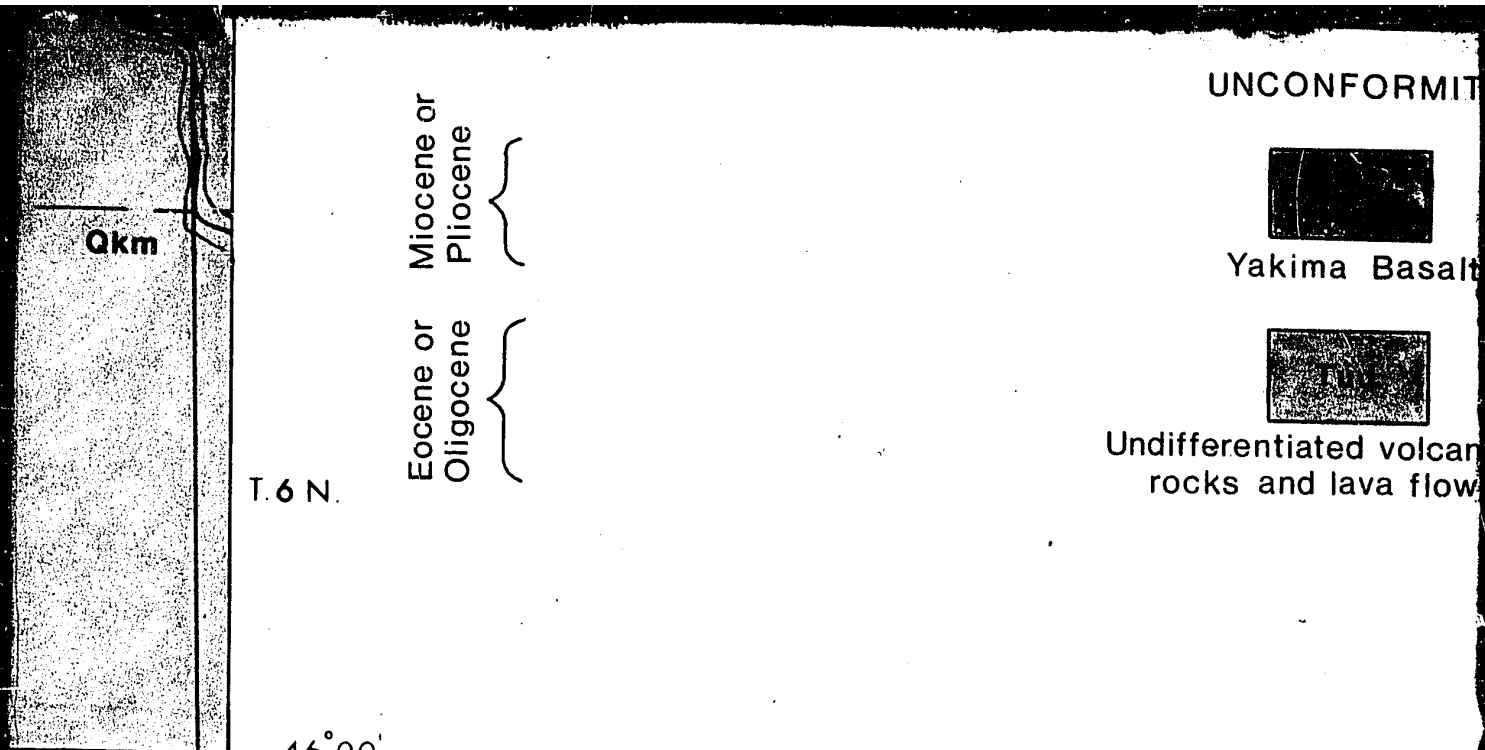
SCALE



CONTOUR INTERVAL 500 FEET

EAST SLOPES OF MOUNT ADAMS VOLCANO

By
Kenneth D. Hopkins
 1976



UNCONFORMIT

Miocene or Pliocene

Eocene or Oligocene



Yakima Basalt



Undifferentiated volcanic rocks and lava flows

Qkm

T.6 N.

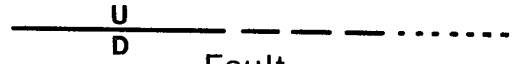
46°00'

oped in 1967-69



Contact

Dashed where approximately located, short dashed where inferred



Fault

Dashed where approximately located, dotted where concealed. U, upthrown side; D, downthrown side

5 MILES

TERS

ADAMS VOLCANO, WASHINGTON

County, Park Olivas Basin
Qcp, flows
Qcpt, tephra cones

TERT
QUAT

UNCONFORMITY



Yakima Basalt



Undifferentiated volcaniclastic
rocks and lava flows

TERTIARY

located,
red

Approximate maximum extent of glaciation,
where not marked by prominent end
moraines, during McDonald Ridge time.
Dots included where inferred

located,
U, upthrown

Flow margin
Flow overlaps older flows of same
rock unit. Hachures drawn on
younger flow. Not mapped inside
McDonald Ridge Drift border

ON