AN ABSTRACT OF THE THESIS OF

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The thesis area consists of approximately thirty square miles in the Southern Cascades of Washington near Mount Adams.

The oldest exposed rocks are sedimentary volcanic clastics and pyroclastic flows of late-Oligocene age that form a homocline in the northwest corner of the area. A thick pile of younger Tertiary lavas, mudflows, and volcanic clastics unconformably overlie the Oligocene rocks, and contain two hydrothermally altered zones. Andesitic lavas from Mount Adams lap onto older rocks and are of Recent to Pleistocene age. Two glacial till deposits and two airfall pyroclastic layers are present throughout the area.

One major fault and two broad folds are present in the area.

The geothermal potential is not believed to be great, because genetic relationships indicate the hydrothermal systems that produced the two alteration zones were active only in pre-Pleistocene time. There are no external manifestations of a

presently active hydrothermal system with geothermal potential.

Geology of Babyshoe Ridge Area, Southern Cascades, Washington

by

David Sig Harle

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GEOLOGY OF BABYSHOE RIDGE AREA,
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INTRODUCTION

Location and Accessibility

The area of investigation is located in south-central Washington, near the northwest flank of Mount Adams. The area is approximately thirty square miles, and is centered on lat 46°15' N., long 121°37'30" W. in Skamania County, Washington (Figure 1). It includes parts of T. 9 N. and Rs. 9 and 10 E.

The area may be reached from the south by U. S. Forest Service road # N84 and from the north by U.S. Forest Service road # 123. Spur roads # N925, 101, and 1016 provide access to other parts of the area.

Objectives

The main objectives of this thesis are:

1. To provide a detailed geologic map of the specified area.
2. To describe lithologic units, structure, and stratigraphy.
3. To establish the geologic history of the area and its relation to regional geology.
4. To determine if the geothermal potential of the area warrants further investigation through geophysical and geochemical methods.

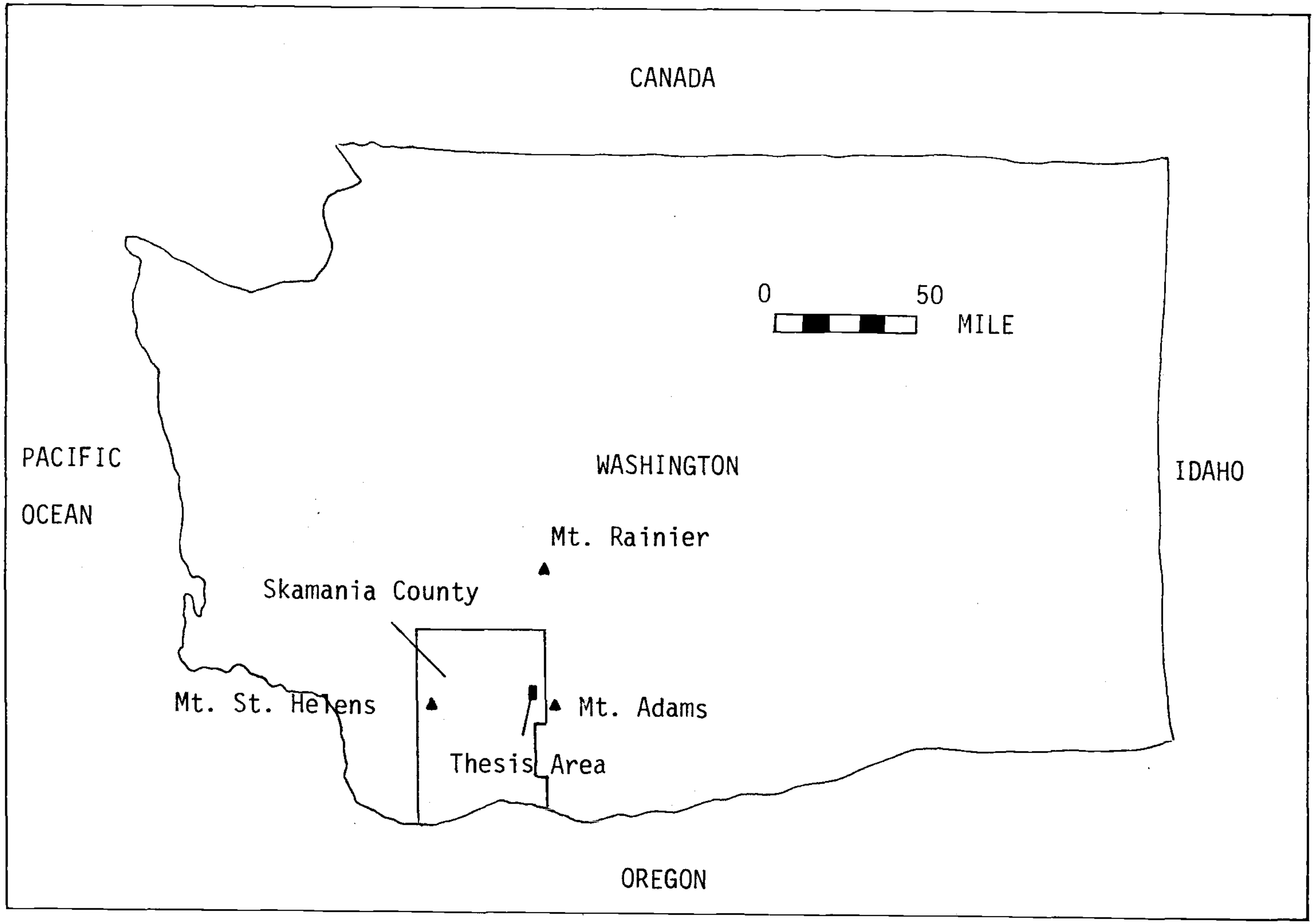


Figure 1. Location of thesis area.

Methods of Investigation

Field work was conducted during July, August, and September, 1973. The base map is a composite of four United States Geological Survey, seven and one-half minute quadrangle maps: East Canyon Ridge, Green Mountain, Mount Adams West, and Steamboat Mountain. Rock unit contacts were located with the help of an altimeter, and attitudes were taken with a Brunton Compass. High altitude, 1:63,000, aerial photographs and Earth Resources Technology Satellite (ERTS) imagery were used to provide an overview of the area's topography and structure.

More than one-hundred rock samples were taken to be used for laboratory studies which were completed during September 1973 - March 1974. Laboratory work involved the microscopic examination of thin sections and samples with petrographic and binocular microscopes. The Michel-Levy method was used to determine plagioclase composition. Whole rock chemical analyses were done by Mrs. Ruth Lightfoot and Dr. E. M. Taylor (OSU Geology Department) using x-ray fluorescence spectrometry (FeO, CaO, K_2O, TiO_2), atomic absorption spectrophotometry (MgO, Na_2O), and the colormetric method of visible light spectrophotometry (SiO_2). Trace element analyses were determined colorimetrically (Mo) and through atomic absorption (Pb, Zn, Cu) by Rocky Mountain Chemical Corporation. The methods used did not allow for the determination of H_2O, and all iron is reported as FeO.

Terminology

Igneous rocks are classified according to Williams, Turner, and Gilbert (1964). Colors are in accordance with the "Rock Color Chart" (Goddard and others, 1963). Classification of volcanic sediments and rocks used in this thesis follow Fisher (1961).

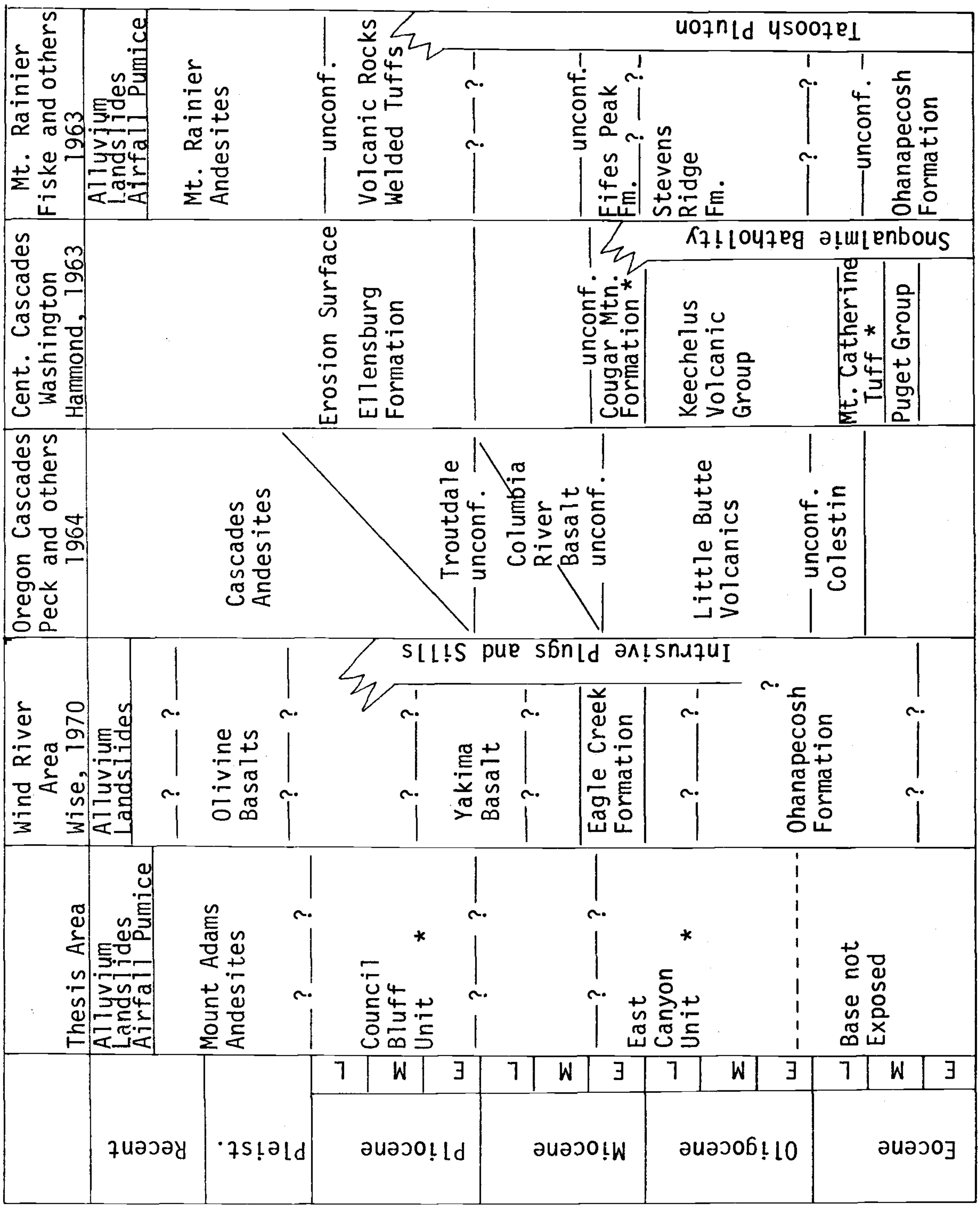
Geologic Setting

The Southern Cascade Range forms a province characterized by Quaternary volcanoes built on a thick platform of Tertiary supracrustal and intrusive rocks. This geologic province extends southward from the North Cascade Range to the Klamath Mountains and Sierra Nevada Range. The North Cascades are composed predominately of pre-Tertiary metamorphic rocks and late Cretaceous-Tertiary intrusive rocks. Miocene-Pliocene basalts, forming the Columbia River Plateau, borders the Cascades on the east. On the west, the Puget Lowlands consist of Tertiary sedimentary and volcanic rocks of predominately marine origin. Plate 2 shows some of the formally and informally named rock units in and around the thesis area.

Mount Adams is a Quaternary stratovolcano near the thesis area, that is built unconformably on a base of Tertiary lavas and other rocks of volcanic origin.

Plate 2. Rock units previously described in the Central Cascades, Oregon and Washington.

* informal name



Previous Investigations

I. C. Russell (1893), A. R. Grant (1969), and Bates McKee (1972) briefly described the geological framework of the Southern Cascade Range of Washington. The early Tertiary stratigraphy of some regions adjacent to the thesis area is discussed by W. C. Warren (1936), Jean Verhoogen (1937), R. J. Foster (1960), A. C. Waters (1961), R. S. Fiske and others (1963), and W. S. Wise (1971). Pleistocene to Recent volcanism in the Washington Cascades is outlined by Boque and Hodge (1940), and R. A. Sheppard (1967) describes a lava flow from Mt. Adams. The glacial history of Washington is summarized by D. R. Crandell (1965). Airfall pyroclastic deposits in Washington have been discussed by D. R. Crandell (1962), G. K. Czamanske (1965), and Keith Randle and others (1971). M. T. Hunting and others published a 1:500,000, geological map of Washington in 1961.

STRATIGRAPHY

The map area is divided into an eastern one-third and a western two-thirds according to the bedrock age.

The eastern part contains Recent to Pleistocene andesite lava flows. Mount Adams is the source for these lavas that show primary dips toward the northwest. Four flows have been distinguished, and they lap onto older rocks to the west. These lavas extend to the north, south, and east of the thesis area.

In the western part, the rocks that form Council Bluff and extend southward beyond the thesis area are informally called the Council Bluff unit. This unit is a thick sequence of Tertiary lavas, autoclastic breccias, and mudflows of basaltic andesite to basalt composition. North of Council Bluff, in the northwest corner of the area, lies the oldest rock unit, a thick sequence of bedded volcanic sandstones, siltstones, mudstones, breccias, and pyroclastic flows. These rocks, informally called the East Canyon unit, are believed to be correlative to the Stevens Ridge Formation.

Glacial till blankets many of the valleys, and forms morainal features on some of the Quaternary Mount Adams lavas. Airfall deposits of volcanic ash and pumice are preserved in the area. Small ribbons of alluvium have accumulated along some streams where gradients are low enough to allow flow plain deposits to form. Colluvium has collected at the base of the prominent cliffs, and tends to obscure many contacts. Landslide deposits occur in two locations: one formed Council Lake, and the other slide produced a prominent scarp one mile long and 200 feet high in the southwest corner of the area (Sec. 27, T. 9 N., R. 9 E., Appendix 3).

Plate 3 summarizes the stratigraphic units in the Babyshoe Ridge Area.

East Canyon Unit

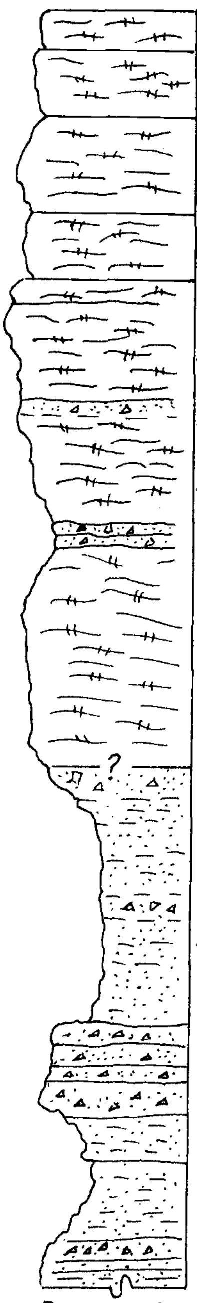
Approximately one-fifth of the area is underlain by a sequence of bedded sedimentary and pyroclastic rocks. A stratigraphic section of the East Canyon unit measured along U. S. Forest Service road # 1016, totals 955 feet (Appendix I). Ninety percent of the unit is composed of volcanic clastic rocks assuming that the covered interval in the measured section is this rock type. The remaining 10 percent is formed by pyroclastic flows. The total thickness of the unit in the area calculated from average strike, average dip, and outcrop extent is approximately 1600 feet.

Field Relationships

The East Canyon unit crops out north of Council Bluff. The attitudes of the bedding average N. 50°W., 30°SW, with the dip decreasing to 25°SW at the base of Council Bluff. The unit dips below the Council Bluff unit to the south, and crops out several miles south of the thesis area (P. E. Hammond, oral communication, 1973). In the east, the East Canyon unit is covered by the Olallie

Plate 3. Stratigraphic Units in Babyshoe Ridge Area.

Surficial Deposits
Airfall pyroclastic deposits: two layers
Alluvium ana colluvium: floodplain and landslide deposits
Glacial till: morainal and outwash deposits



SYM	AGE	DESCRIPTION
		Mount Adams Lavas
Q_1	Post Pleis.	Mutton Creek flow: pyroxene andesite porphyry
		conformable
P_1	Pleistocene	Takhlakh Lake flow: pyroxene andesite porphyry
		conformable
P_2		Olallie Lake flow: pyroxene andesite porphyry
		conformable
P_3		Porphyritic pyroxene flow
		angular unconformity
T_b T_m T_{vc}	Pre-Pleistocene	Council Bluff unit: volcanic flows, autoclastic breecias, mudflows, and lenses of volcanic clastic rocks; composition is basaltic andesite to basalt.
		contact not exposed
T_s	Early Oligocene-Pilocene (34.0 $\pm$ 1.2 million years, Fischer 1971)	East Canyon unit: well-bedded sequence of volcanic clastic rocks ranging from mudstone to breccias; generally light colored containing euhedral quartz and plagioclase grains.

Base not exposed

Lake andesite. The extent of the East Canyon unit to the north and west beyond the thesis area is unknown.

Lithology

The East Canyon unit consists of pyroclastic flows and volcanic clastic rocks. Most of these rocks contain feldspar crystals and rock fragments, and are generally light colored. The colors range from light tan to light green, including rare black mudstones with high carbon content.

The absolute position of the different members within the East Canyon unit cannot be determined, because neither the top nor base of the unit is exposed in the thesis area. Appendix 1 shows two pyroclastic flows in the lower part of the measured section and a thinner one in the upper part. Volcanic clastic rocks are most abundant in the upper part, and the covered interval suggests non-resistant siltstones and mudstones.

Pyroclastic Flows. Distinctive features of the East Canyon pyroclastic flows are their generally light color, abundant pumice fragments, and euhedral plagioclase crystals. Their colors on fresh fractures are white to dark gray, and weathered surfaces are tan to gray. The fresh rock is extremely firm, while the weathered rock is softer, and may be fissile.

Secondary calcite has indurated the flows that appear to have been poorly welded. The thickest pyroclastic flows are approximately 60 feet, but some flows are only 20 feet thick. The thicker flows exhibit well-developed planar joint sets. Figure 2 shows at least two joint sets intersecting at about 60° to one another.

Phenocrysts from 10-20 percent of the pyroclastic flow rocks. The most common phenocryst is euhedral to subhedral plagioclase, which shows normal zoning. The average composition is An_{45}, with a range from An_{38} to An_{54}. Subhedral pyroxene (augite) and magnetite are present, but form only five percent of the rock.

The framework consists of pumice fragments, glass shards, and rock fragments, and can make up to 65 percent of the flow rocks (Figure 3). Pumice fragments average five centimeters in diameter, but may exceed 10 centimeters. Foreign rock fragments appear throughout the flows, and are of basaltic or andesitic composition. They rarely exceed four centimeters, and average two centimeters in diameter.

Volcanic Clastic Rocks. The East Canyon volcanic clastic rocks are composed of fragments ranging from 10 centimeters in diameter to sand- and silt-sized particles. The finer-grained material is the most common. The beds range in thickness from less than one centimeter to more than two meters, and average 30 centimeters thick. The thickest beds are mudstones and siltstones. Cross-bedding and cut and fill structures are found but rarely, as are other evidences of fluvial deposition.

Plagioclase crystals, pumice lapilli, and fragments of glassy lava compose most of the identifiable clasts. Devitrifying glass shards usually form the matrix, and calcite constitutes the cement for these rocks.

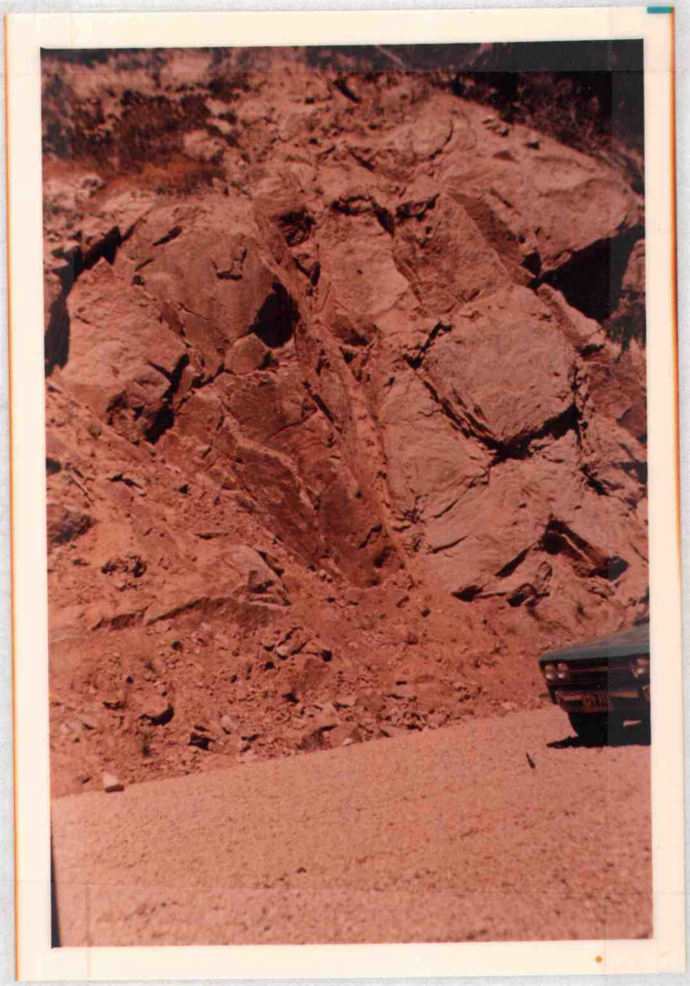


Figure 2. East Canyon unit: light-colored pyroclastic flow, 60 feet thick and showing two planar joint sets intersecting at approximately 60° to one another. Location 1, Appendix 3.

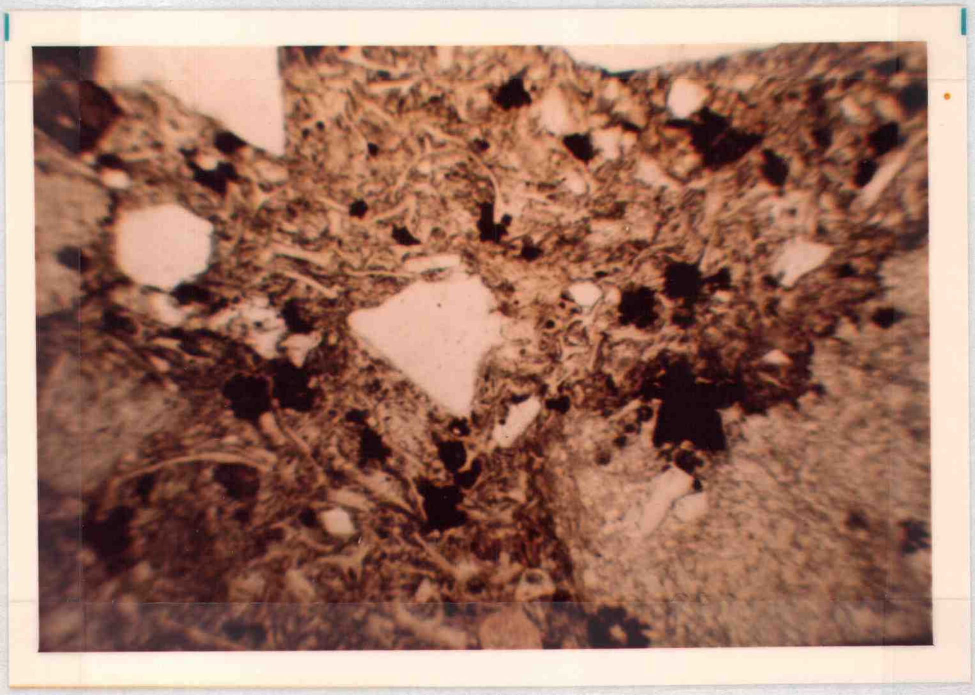


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Figure 3. East Canyon unit pyroclastic flow: euhedral plagioclase, pumice fragments in a matrix of bubble walls, glass shards, and dust. Nicols parallel. Unit 3, Appendix 1. Location 1, Appendix 3.

Origin

The textures and sedimentary structures in the clastic rocks indicate a quiet water environment. Graded, poorly-sorted beds could be from turbidity currents, and the better-sorted, thinner layers from rapid-settling ashfalls in a water-filled basin. Masses of suspended ash in a water-filled basin could have formed the structureless, six to eight feet thick beds of fine tuff, if the supply of ash was long-lasting. Cut and fill structures, cross-bedding, and other current indicators are conspicuously lacking.

The debris in pyroclastic flows of the East Canyon unit shows delicate glass shards and bubble walls as if it was newly erupted and fragmented by contemporaneous volcanic explosions. The low degree of welding, lack of flattening and orientation of pumice fragments, and the great variety of rock fragments spread vertically and horizontally throughout the individual flow units make the conventional ashflow origin difficult to justify. A waterlaid origin is improbable, because glass shards and bubble walls would be destroyed by water action. No sorting, grading, internal bedding, or other indicators of water deposition were observed.

Fiske (1963) describes subaqueous pyroclastic flows in the Ohanapecosh Formation near Mount Rainier, Washington, He describes these flows as originating by the sloughing of debris from the flanks of active underwater volcanoes during and after pyroclastic eruptions. His physical description of the formation is similar to the lithologies observed in the East Canyon unit with the exception that lava flows, indicating a near by vent, are present in the Ohanapecosh Formation. The East Canyon unit could possibly be a part of the genetic sequence described by Fiske that was deposited at a distance from the vents or before subaerial lava flows formed.

Before the origin of the East Canyon unit will be understood fully, a study revealing the unit's extent, lateral variation in lithology, and compositional variations will have to be conducted. The origin will have to be low temperature (less than intense welding temperatures), freshly erupted, and be closely linked with quiet water deposition.

Age and Correlation

Fossils diagnostic of age were not found in the East Canyon unit. Some of the structureless siltstone and mudstone beds along U. S. Forest Service road #1016, yielded a few conifer needles and twig impressions in association with large partially silicified trees. It is possible that further examination of this locality might provide enough material for a paleobotanical date.

Within the thesis area, the East Canyon unit lies stratigraphically below pre-Pleistocene lavas. The regional distribution of the unit indicates that it is in the approximate stratigraphic position of the Stevens Ridge Formation (P. E. Hammond, oral communication, 1973). Except for the lack of quartz crystals, the lithology and petrography compare favorably with the Stevens Ridge Formation described by Fiske and others (1963) and Fischer (1971). The lack of quartz does not invalidate the correlation, because only part of the Stevens Ridge Formation is quartz-rich (Hammond, 1974). Only further mapping on a regional basis will confirm or refute this correlation.

Fischer (1971) dated the Stevens Ridge Formation in the White River-Carbon Ridge area, Washington by potassium-argon methods, and believed it to be of early Oligocene age (34.0 ± 1.2 million years).

Council Bluff Unit

Approximately one-half of the area is underlain by a thick basaltic-andesitic volcanic unit. Lava flows and autoclastic breccias form approximately 80 percent of the unit. Mudflows and debris flows, some exhibiting crude bedding, make up approximately 18 percent of the unit. Small lenses of mudstones, siltstones, and conglomerates, composed of volcanic fragments, are scattered throughout the unit, but comprise less than three percent of the total unit.

Field Relationships

This volcanic unit is bounded on the east by the younger Mount Adams lavas, that lap over it. The Council Bluff unit lies unconformably above the East Canyon unit which bounds it on the north and south. The angular unconformity is covered by vegetation, talus and glacial till. It is inferred to exist by the change in dips of individual beds and flows from north to south across the contact between the units. Dips average 30° SW in the East Canyon unit, and are exposed within approximately 1000 feet of the contact (SW 1/4, SW 1/4, T. 9 N., R. 9 E., Appendix 3). Council Bluff lava flow, T_{b2}, shows a dip of 10° SW just south of the contact (Plate 1). An angular unconformity of approximately 20° is present, if the above dips are projected to the contact between the unit. The estimated thickness of the Council Bluff unit is 1500 feet.

A partial cross-section of this volcanic pile can be seen in the resistant cliff of Council Bluff. Here, several flows autoclastic breccias, and mudflows are present. The pile was deposited on a surface of considerable relief, and as the pile grew, the irregular topography of the flows served as a base for later flows. The topographic relief is as much as 40 feet in some exposures in Council Bluff. Along U. S. Forest Service road # N84, several flows have exposed bases that conform to the topography of their channels of deposition.

Outcrop Expression

Lava flows have the most erosionally resistant aspect of the various rock types represented within the unit. Table Mountain and some other nearby hills form mesas capped by single flows of approximately 70 to 100 feet in thickness (Figure 4). The prominent

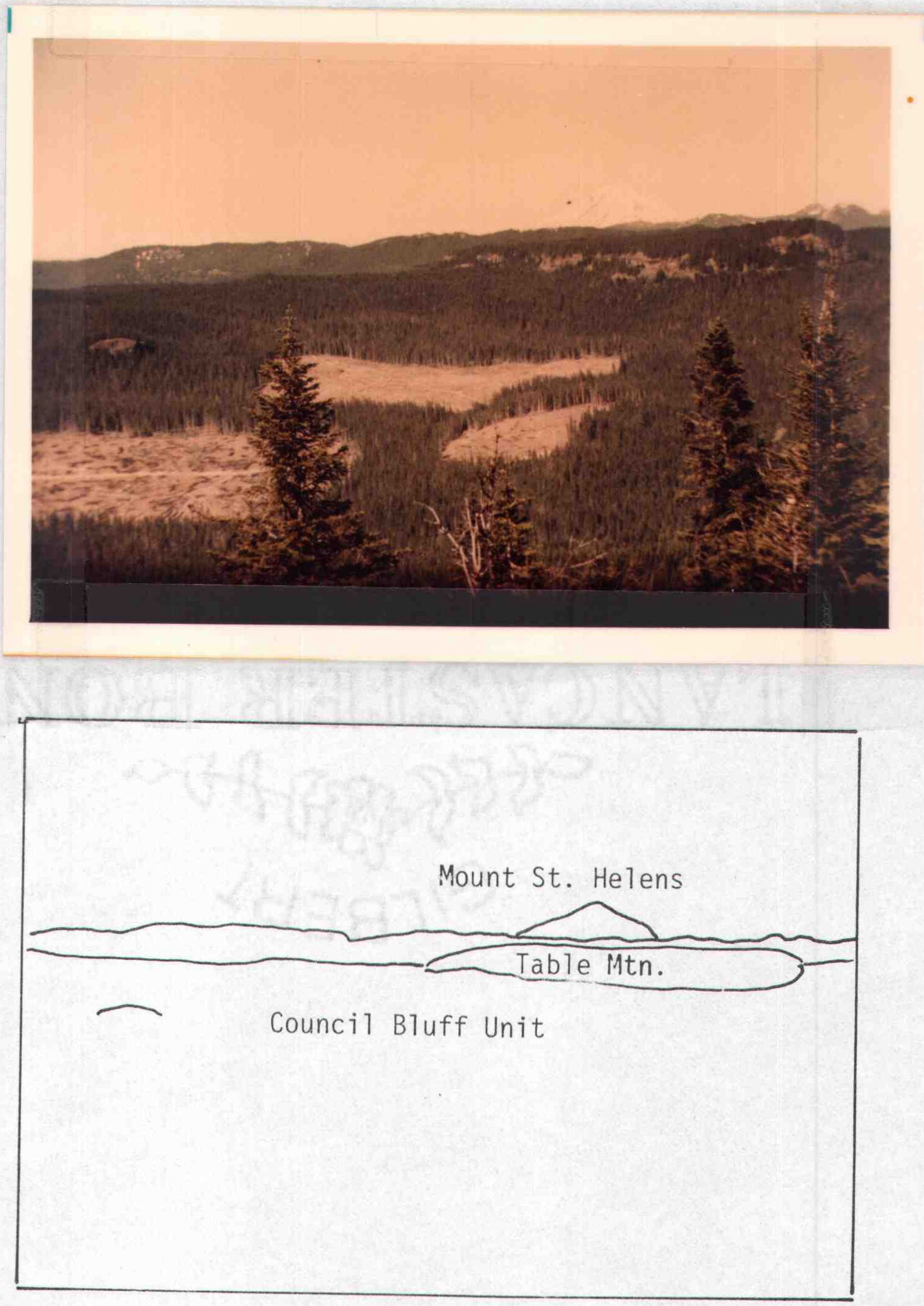


Figure 4. Looking west towards Mount St. Helens from Council Bluff (Location 3, Appendix 3). Table Mountain is formed by a resistant flow of basaltic andesite in the Council Bluff unit.

cliffs along the edges of these landforms always have associated talus slopes formed by the platy debris of these rocks. Flows along Boulder Creek show particularly well-developed platy jointing.

Volcanic breccias, 50 feet thick, are interbedded with lava flows in Council Bluff and along Boulder Creek (Figure 5). Mudflows and autoclastic breccias are impossible to distinguish in many outcrops, because both are monolithologic, and have similar outcrop expression. Upon weathering and erosion, they both take on a rounded hoodoo form indicating rocks that are less resistant than the lava flows. Invariably, every lava flow has an associated basal breccia, which incorporates fragments of the underlying rocks. The landslide in the southwest corner of the area exposes a sequence of lava flows 50 to 60 feet thick, with 5 to 10 feet thick breccia zones between the flows in the volcanic pile (Figure 6).

Petrography

The basaltic andesites and andesites are prophyritic with phenocrysts of plagioclase, hypersthene, augite, and magnetite set in a groundmass of plagioclase microlites, pyroxene, and occasionally volcanic glass. The dark brown glass is usually fresh, but is partly devitrified in a few samples. Phenocrysts make up 25 to 35 percent of the rock, and occur as small glomeroporphyritic clusters as well as individual minerals. Some rocks with hemicrystalline groundmasses have slightly pilotaxitic texture, but

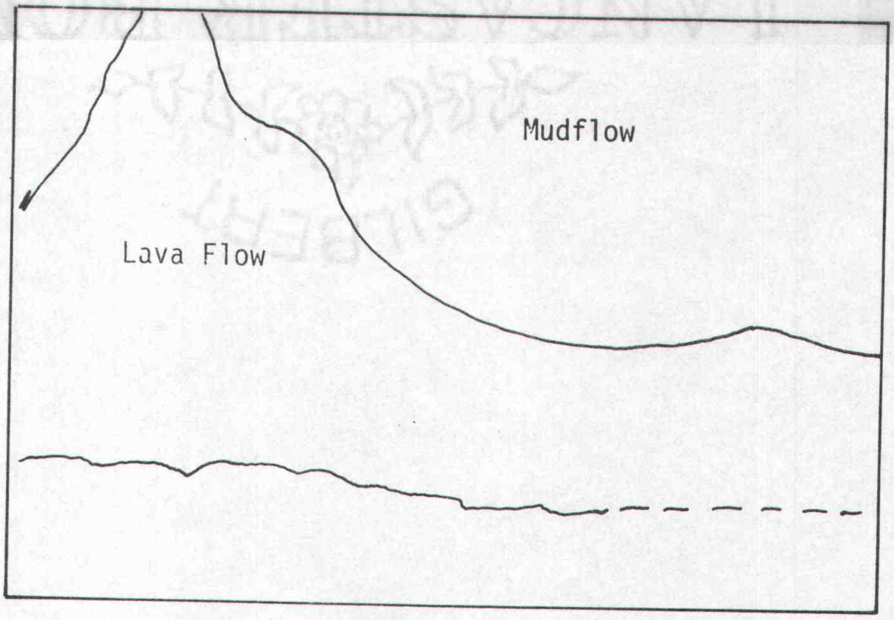


Figure 5. Council Bluff unit: mudflow overlying lava flow along Boulder Creek (Location 3, Appendix 3). Contact is sharp and reveals the shape of confining channel of deposition.

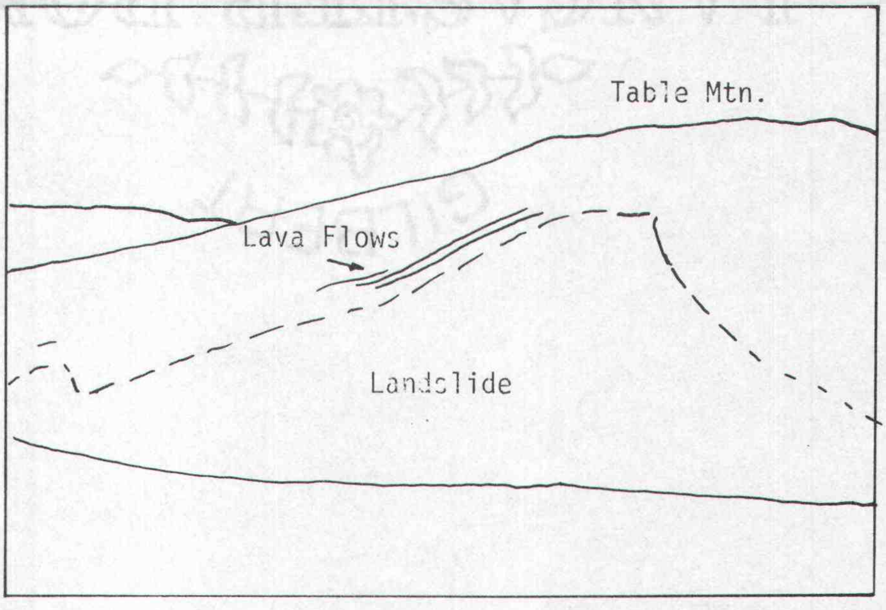


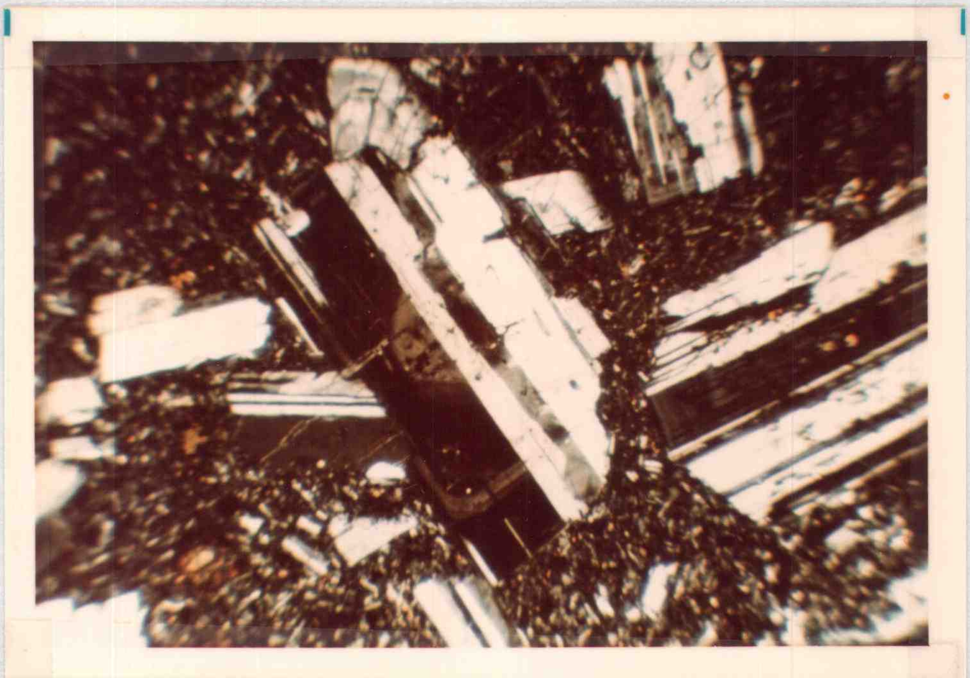
Figure 6. Looking west toward the southwest corner of the thesis area from USFS road # N84 (Location 4, Appendix 3). Sequence of lava flows revealed in the scarp of a landslide block.

most groundmasses are holocrystalline, and show a felty or intergranular texture.

Plagioclase phenocrysts are subhedral to euhedral, zoned, and show polysynthetic twinning. The zoning is primarily normal with the cores (An_{55-50}) sharply bounded by the rims (An_{30-28}). Plagioclase in the groundmass is of the same composition as the more sodic rims of the phenocrysts. Sample # 39-73 appears to have reverse compositional zoning in the form of an internal rim that goes to extinction simultaneously with the core. In Figure 7 the more calcic core and the rim are lighter colored than the rest of the crystal which is at extinction under crossed nicols. Many of the plagioclase phenocrysts are poikiolitic with inclusions of volcanic glass and pyroxene grains.

Augite and orthopyroxene occur as individual phenocrysts and as part of glomeroporphyritic clusters. The augite is pale tan, subhedral to euhedral, and generally smaller than plagioclase phenocrysts. The 2V angle ranges from 55° to 60°, and is positive. The orthopyroxene shows very slight pleochroism of light brown to tan, parallel extinction, and lower birefringence than the clinopyroxenes. Its 2V angle ranges from 55° to 60°, and it is negative.

Samples D-20 (Figure 8) and 6-73a (Location 6, Appendix 3) have orthopyroxene crystals surrounded by clinopyroxene. The two pyroxenes in these phenocrysts appear to be the same as single pyroxene phenocrysts elsewhere in the samples. Twinning is continous across these pyroxene phenocrysts through their core and



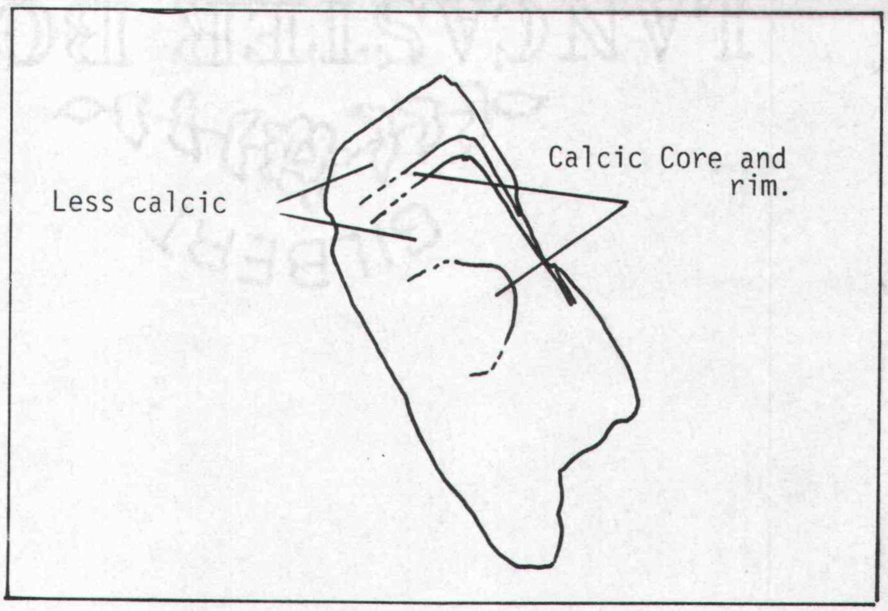


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Figure 7. Complex zoning in twinned plagioclase phenocryst. Core and rim are lighter color while the surrounding crystal is at extinction. Nicols crossed. Sample #39-73 (Location 5, Appendix 3).

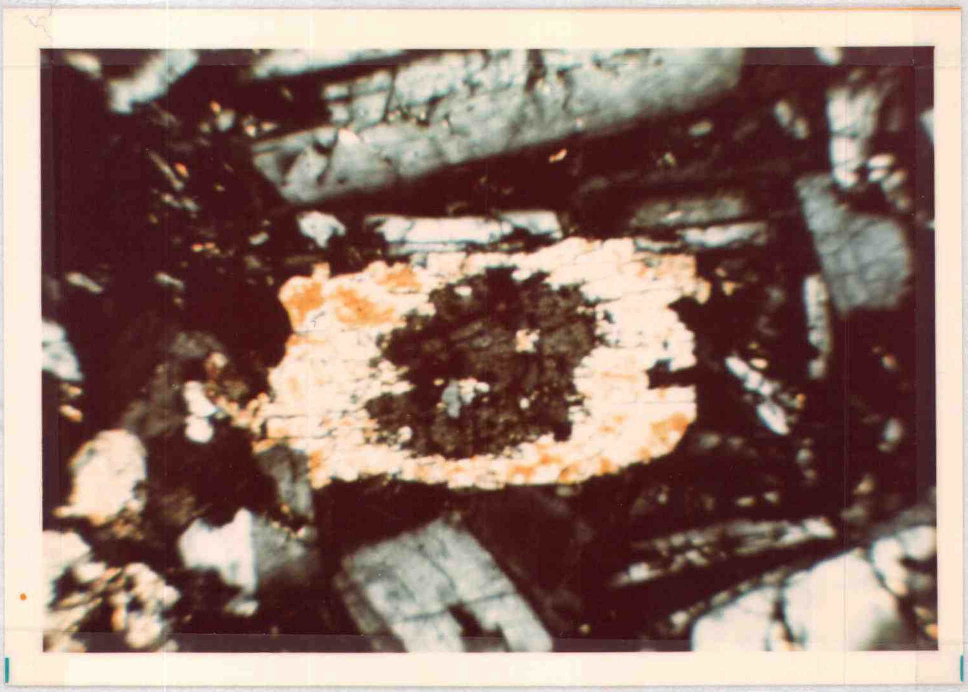

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Figure 8. Reaction rim: orthopyroxene core is at extinction, surrounded by clinopyroxene (yellow). Nicols crossed. Sample # D-20 (Location 6, Appendix 3).

rim. The reaction rim is probably due to Fe^{+2} substituting for Mg^{+2} during normal crystallization of the melt (Deer and others, 1966).

Pyroxene is altered to chlorite in many samples. The chlorite is non-pleochroic, has low birefringence, and is green in color. The chlorite alteration usually occurs along fractures and on outer boundaries of pyroxene crystals. In pyroxene phenocrysts that have been completely altered, magnetite is commonly concentrated near the edge of the crystal.

Some plagioclase is partially altered to calcite. Also, calcite occurs as secondary cavity fillings and as small veinlets less than one millimeter thick. Some of the glass has been altered to clay minerals, nontronite or celadonite. The clay minerals are orange, earthy, cavity fillings, showing radiating spherulites with slight birefringence (Figures 9a, 9b).

Origin

Definite source areas for the Council Bluff volcanics cannot be designated from field or laboratory evidence. More than one source area was probably involved. Cross-bedding in mudflows exposed in Council Bluff suggest an easterly source area. Also, indirect information points to a volcanic source area near the top of Table Mountain that lies on the axis of the Table Mountain anticline. The factors indicating a volcanic center at this location are listed below:

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Figure 9a. Clay mineral: a cavity filling in glassy groundmass of basaltic andesite. Nicols parallel. Sample #31-73 (Location 7, Appendix 3).

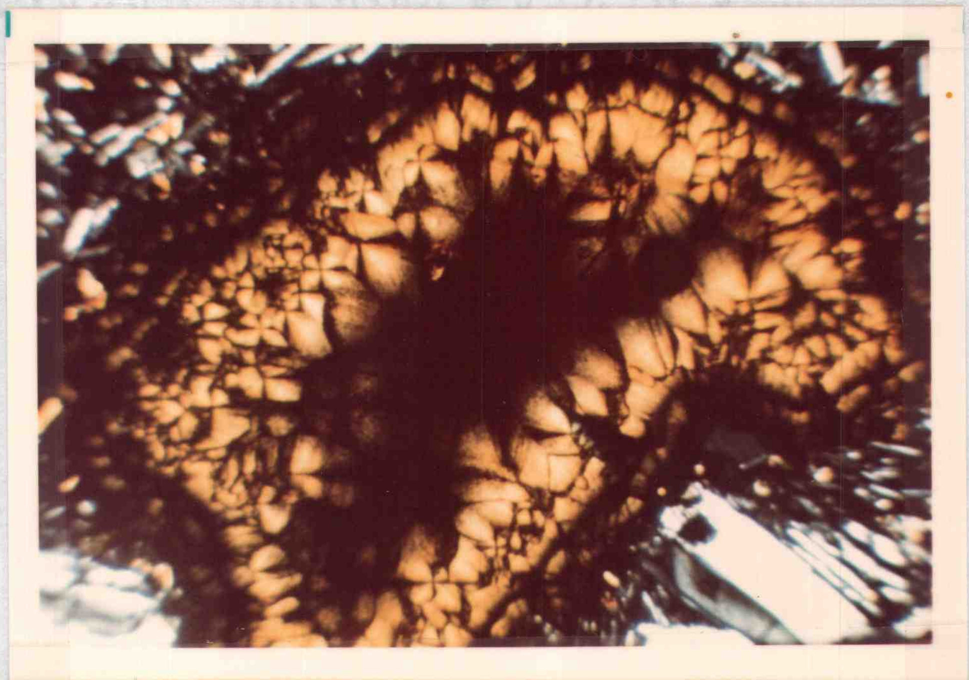

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Figure 9b. Same as Figure 9a, but with nicols crossed; isotropic center of the cavity filling and spherulitic border are visible.

1. The flows that outline the nose of the southeast plunging anticline dip away from the proposed volcanic center, and could possibly reflect primary dips.
2. Cinder talus slopes (Figure 10) were found near the proposed volcanic center.
3. Intensive hydrothermal alteration and pyrite mineralization was found adjacent to the proposed volcanic center.
4. A vertical rock body transgresses the gently dipping lava flows near the volcanic center (Figure 11).
5. Petrographically, the rock found in the plug-like body is identical to the surrounding flows, except that it is more severely altered. The groundmass has been altered to a potassium-rich clay, taking on a light gray color, and magnetite is changed to hematite and limonite. Many iron-stained, fine-grained xenoliths are present throughout the rock.

Confirming evidence of an eruptive center such as contact relations and associated dikes were not found due to vegetation cover. Also, the regional distribution and abundance of mudflow versus lava flows within the Council Bluff unit needs to be studied to confirm this hypothesis.

Figure 10. Cinder talus slopes on Table Mountain near the proposed volcanic center. (Location 8, Appendix 3)

Figure 11. Plug-like rock body composed of porphyritic basaltic andesite identical to surrounding Council Bluff lava flows. Looking south to Table Mountain from Location 2, Appendix 3.

Mount Adams Lavas

Mount Adams volcano has been the source for at least four flows in the area. The flows are part of the volcano's flanks which extend into the area from the summit approximately six miles to the southeast. The flows are depicted by P_3, P_2, P_1, and Q_1 in the generalized geologic column (Plate 3). The flows were deposited on a terrain with relief up to 1000 feet, and are confined to the shape of old drainage channels and other topographic lows. Maximum thickness of the four flows is approximately 800 feet.

Field Relationships

The oldest flow, P_3, has the smallest exposure area, and is stratigraphically below P_2. The "V"-shaped outcrop pattern is the result of erosion of the gently dipping flow by the Lewis River (Plate 1 and Location 9, Appendix 3). The flow is of a compound nature with a later surge of lava overriding the first part of the flow. The two parts of the lava flow have identical lithology, and are separated by a 10 feet thick rubble zone. The base of P_3 is not exposed, but glacial till and interglacial fluvial sediments lie on top of the flow.

The second oldest flow, P_2, termed the Olallie Lake andesite, is a prominent ridge and cliff former along the eastern edge of the Lewis River drainage in the area. Also, the flow forms the platform for the Chain of Lakes, Olallie Lake, and Takhlakh Lake. These lakes have formed in depressions in the flow surface. The lower contact of the Olallie Lake flow is comfortable as in cushy? and moderately sharp with P_3. The contact is a rubble zone of approximately three feet thick.

The Takhlakh Lake andesite, P_1, lies conformably on top of the Olallie Lake flow and unconformably on P_3. The main flow goes north into the Adams Creek drainage, but offshoots extend toward the center of the area onto the older Council Bluff unit. Flows down the Riley Creek drainage and the Lewis River drainage are examples of these offshoots (Plate 1). The flow is readily identifiable since it bears relatively sparse vegetation. The average tree growing on its surface is only two or three feet in diameter and windfall trees are relatively scarce. High altitude photographs and ERTS imagery are particularly useful in delineating this flow (Figure 12).

Some parts of the Takhlakh Lake andesite flow surface has been heavily glaciated, and spectacular moranial features were developed. The portion of the flow in the northeastern corner of the area has not been glacially eroded, and still maintains a very rugged surface.

The youngest flow and the only post-Pleistocene flow in the area is the Mutton Creek andesite, Q_1. Only one small lobe of this flank fissure flow extends into the southeast corner of the area, and it has an outcrop exposure of approximately 1000 square feet. Vegetation is sparse, and primary flow lines are still

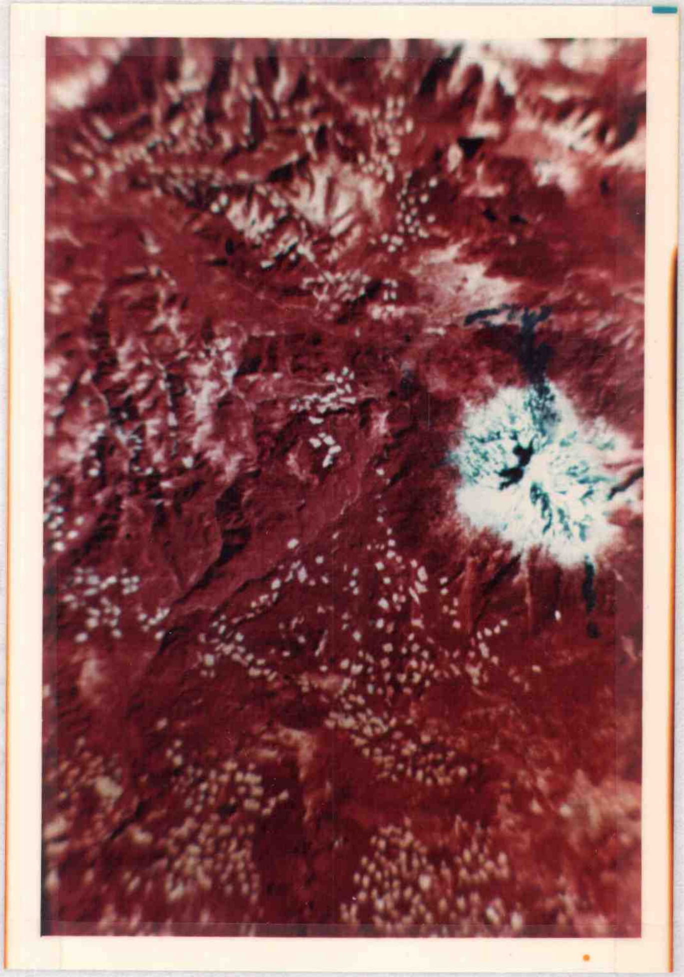


Figure 12. ERTS photograph. Approximate scale 1 in. = 6 miles. Recent lava flows from the volcanoes show as dark blue areas near snow capped summits. North-south lineation is Council Lake fault.

visible. The flow is 50 to 70 feet thick, blocky, and is probably an example of what the other Mount Adams flows looked like before glaciation and erosion.

<u>Nature of the Flows</u>

A complete cross-section through each of the flows was not available in outcrop, but from separate outcrops, a generalized flow cross-section was compiled (Figure 13).

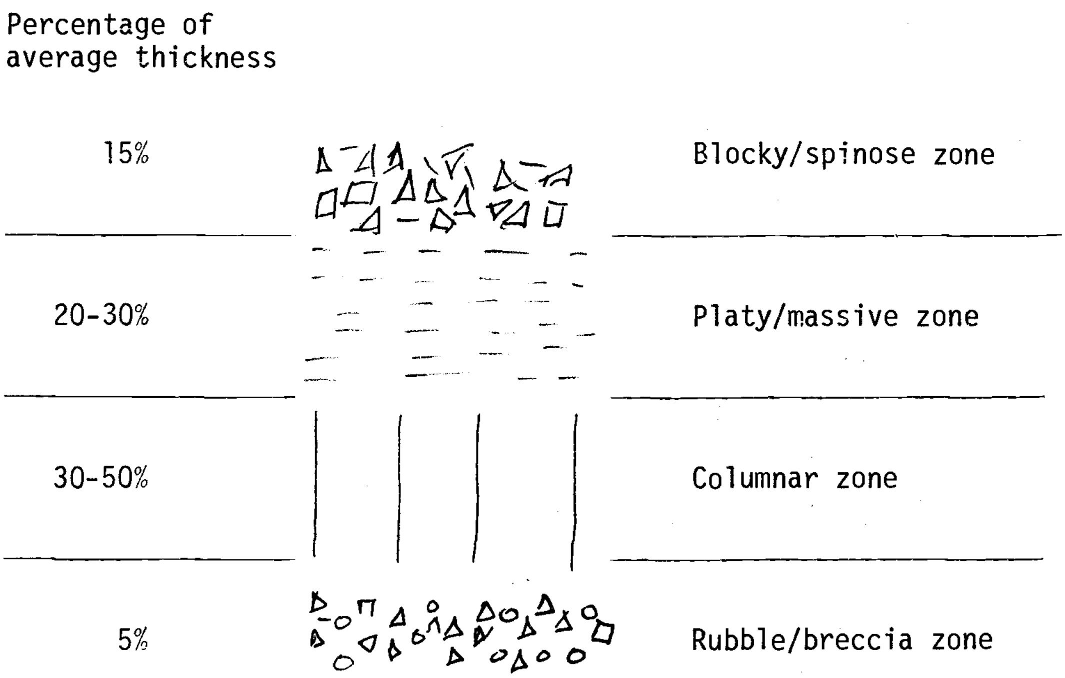


Figure 13.

Probably all of the features defined here occur within each flow, but locally one or two zones may be missing. The best example of the blocky zone is at Tach Tach Meadow, where the Takhlakh Lake flow has a blocky, slightly spinose surface (Figure 14). The platy/massive zone can be seen directly in contact with the columnar zone at the intersection of Big Spring Creek and United States Forest Service road # N84 (Figure 15). The basal rubble/breccia zone is best exposed in the Olallie Lake flow along the Lewis River (Location 9, Appendix 3).

Petrography

The Mount Adams lavas are andesite to basaltic andesite porphyries with phenocrysts of plagioclase, hypersthene, augite, and magnetite set in a groundmass of plagioclase laths, pigeonite, magnetite, and glass. The mineral and phenocryst percentages vary within each flow depending on where each flow was sampled, but field observations revealed:

1. Flow P_3, pyroxene andesite porphyries, contains the lowest percentage of phenocrysts (approximately five percent of the rock).
2. Flows P_2, Olallie Lake flow, and Q_1, Mutton Creek flow, have approximately 10 to 20 percent phenocrysts.
3. Flow P_1, Takhlakh Lake flow, has 20 to 35 percent phenocrysts.

Plagioclase phenocrysts are subhedral, and average two to three millimeters long. Normal zoning is common with calcic

Figure 14. Blocky surface of Takhlakh Lake andesite at Tach Tach Meadow (Location 10, Appendix 3).

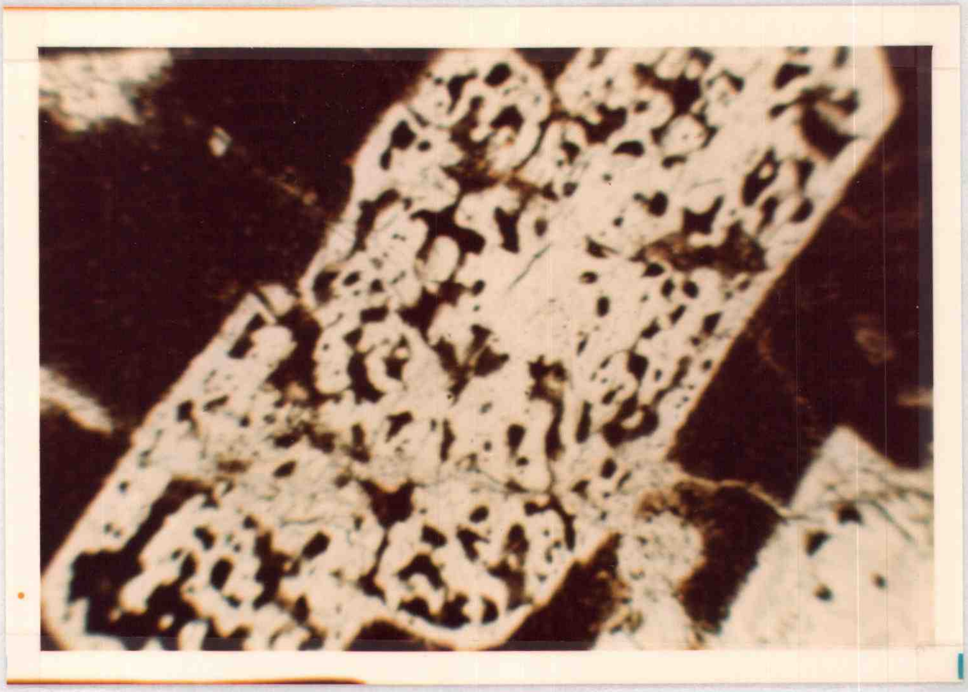
Figure 15. Olallie Lake andesite: platy/massive zone directly over columnar zone. Located at intersection of Big Spring Creek and USFS road # N84 (Location 11, Appendix 3).

cores (An_{60-50}) surrounded by more sodic rims (An_{35-30}). Figure 16 shows resorbtion of the more calcic core by the melt that occurred before cooling (Boque and Hodge, 1940). The internal portion of some zoned plagioclase phenocrysts include grains of volcanic glass and anhedral pyroxene indicating rapid crystal growth. The groundmass plagioclase is usually in the form of microlites, but rarely crystals get as large as 0.1 millimeter long. Compositionally the groundmass plagioclase is the same as the outer rim of the zoned phenocrysts.

The pyroxenes found in the Mount Adams lavas are of three types: augite, hypersthene, and pigeonite. Augite is the most common pyroxene phenocryst, and makes up three to seven percent of the rock. It shows inclined extinction, a 2V angle of 55° to 60°, and is optically positive. Augite phenocrysts appear to be unzoned. Augite phenocrysts are a pale green color, with no pleochroism, and are commonly twinned.

Hypersthene phenocrysts are pleochroic pale green to light pinkish brown, and show parallel extinction. This mineral is optically negative with a 2V angle of 60° to 65°. Some euhedral grains are present, but most are subhedral. Some grains are isolated, but others are included with plagioclase, augite, and magnetite in glomeroporphyritic clusters (Figure 17).

Pigeonite is the third variety of pyroxene. It is probably the most abundant pyroxene in the rock, but most of it is in the groundmass as grains less than 0.1 millimeter in size (Boque and Hodge, 1940). The most striking occurrence of pigeonite is as a



1 mm

Figure 16. Plagioclase phenocryst showing resorbtion texture. Thin rim uneffected by resorbtion was at equilibrium with the melt. Nicols parallel. Sample # M-963 (Location 12, Appendix 3).

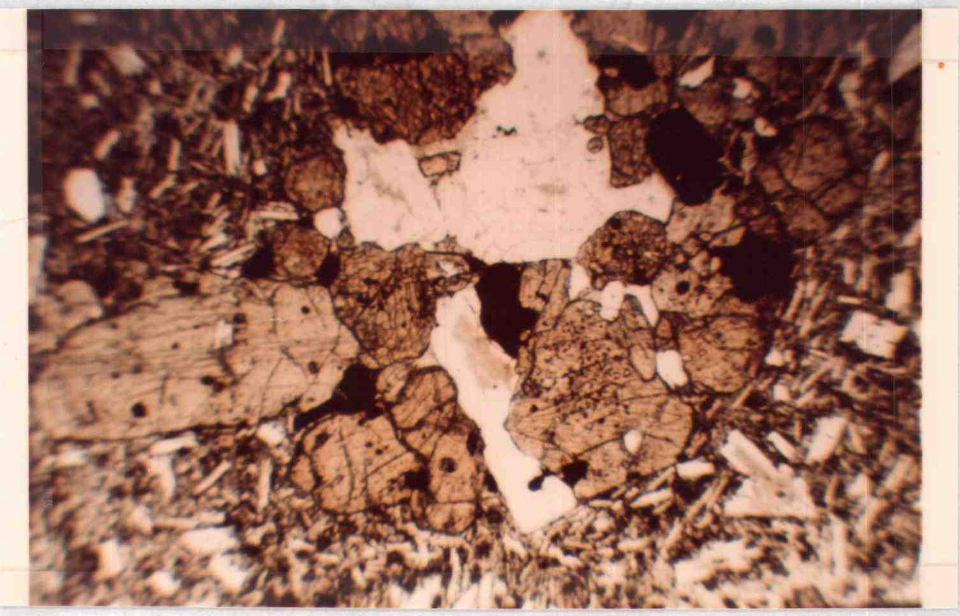


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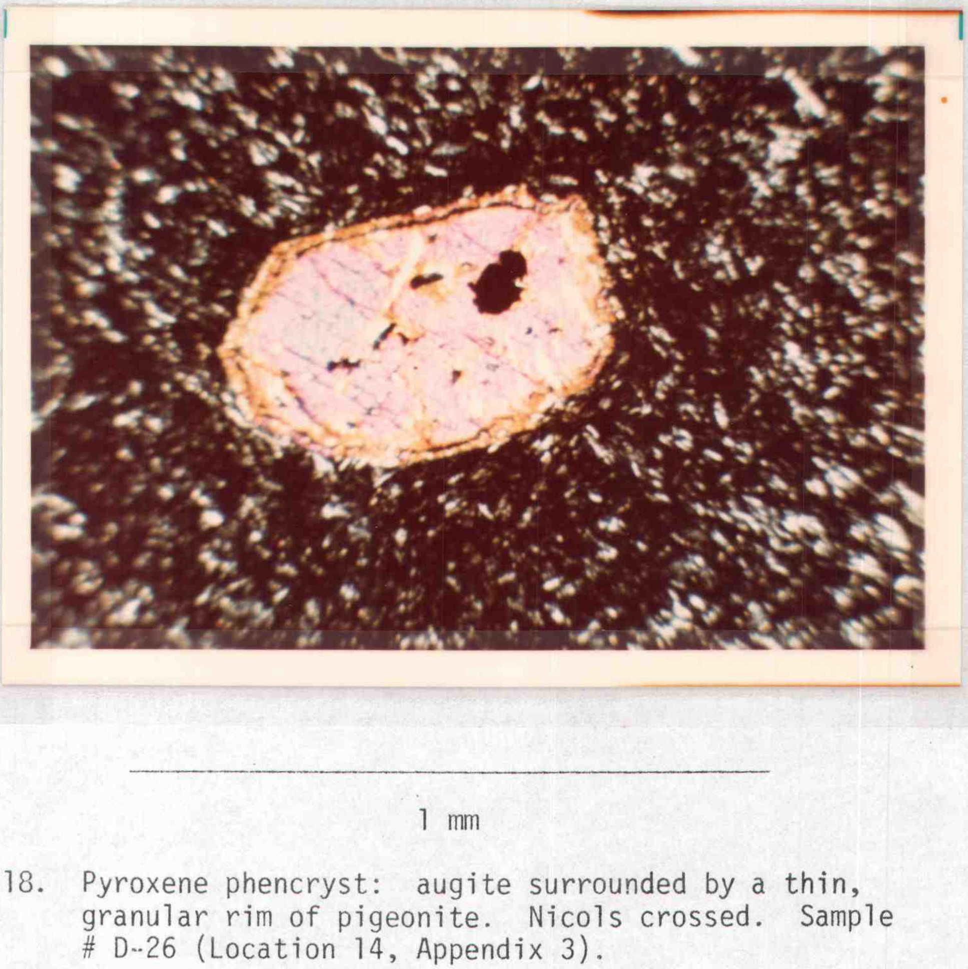
Figure 17. Glomerocryst: Plagioclase, pyroxene, and magnetite in an intergranular groundmass showing slight pilotaxitic alignment of microlites. Nicols parallel. Sample # 27-73 (Location 13, Appendix 3).

thin, granular, reaction rim around augite and hypersthene (Figure 18). The rim's boundary is sharp, but the rims are always optically continuous with the core (Sheppard, 1967). This represents the equilibrium condition at the time of quenching with a high ratio of Mg^{+2} to Fe^{+2}. Under these conditions pigeonite is able to form (Deer and others, 1966).

The groundmasses are intergranular, and always contain volcanic glass. Lavas with high-glass content take on a darker color due to the brown glass, while low-glass lavas are usually light gray. Dichtytaxitic texture is present in some high-glass andesites, where the glassy matrix has evacuated cavities between phenocrysts in contact with each other. The Takhlakh Lake andesite commonly has this texture. Pilotaxitic texture is common in Olallie Lake andesite, where both phenocrysts and microlites have been aligned by flowage stresses. Glomeroporphyritic clusters are common, and are as large as seven millimeters in diameter.

Glacial Deposits

Two glacial deposits were identified in the map area. Older till is located on the north side of East Canyon in road cuts along U. S. Forest Service road # 1016 (Figure 19). A larger amount of younger till was also found. It occurs between P_2 and P_3 and on top of P_2. The major occurrence is as terminal and lateral moraines on top of P_1. Two terminal moraines are cut by U. S. Forest Service road # N84, and lie above the Council Bluff unit (Figure 20).



1 mm

Figure 18. Pyroxene phencryst: augite surrounded by a thin, granular rim of pigeonite. Nicols crossed. Sample # D-26 (Location 14, Appendix 3).

Figure 19. Older glacial till: drift is highly weathered to light brown. (Near Location 15, Appendix 3).

Figure 20. Younger glacial till: a cross-section of a terminal moraine shows the blue-gray color of matrix and unweathered boulders one to two feet in diameter. Location 16, Appendix 3).

Older Drift

The older East Canyon till is a light brown to tan, very compact, unsorted mixture of pebbles and cobbles in a matrix of silt and sand. The till in one exposure is 10 feet thick. Bounders are rare and none are greater than one foot in diameter. The pebbles and cobbles make up approximately 30 percent of the deposit. Where fresh enough to study, the larger rock fragments are found to be of the same composition as the East Canyon unit. Weathering of the exposures is complete due to the process, volcanic clastic rocks which make up the till. Many of the clasts are no more resistant than the matrix, which can be broken easily by a pick.

The Younger Drift

The younger Takhlakh Lake till is a gray to blue-gray, uncompacted, unsorted, and unstratified mixture of cobbles and boulders in a sandy to silty matrix. In contrast to older till, cobbles and boulders make up to 70 percent of the till with boulders as large as four feet in diameter.

The source rocks are the Mount Adams lavas (80 percent) and, to a lesser extent, the Council Bluff unit (20 percent). The gray color is due to the matrix which is very fresh except near the surface soil layer. The bounders ?? kangaroos? and cobbles are also fresh, and show no weathering rinds. Glacial striations are preserved on some of the larger boulders.

Glacial History

The oldest till is believed to be from the Salmon Springs glaciation (Crandell, 1963). The stratigraphic position and physical description fits that of Crandell. The glaciers that shaped some of the primary drainage channels such as the East Canyon and Lewis River Valley, deposited the till. The Olympia Interglaciation period, described by Wright and Fry (1965) is probably represented by the time gap between the two tills. The younger till along with some of the fluvial sands and gravels would then have been deposited during the Fraser glaciation. At least two advances of ice within the area can be identified during this time as indicated by the interglacial lava flow P_2.

Airfall Pyroclastic Deposits

Two layers of Recent pumice and vitric/crystal ash are present as thin sheets mantling ridge tops and locations protected from erosion. Extensive reworking of the original deposits makes it difficult to delineate the individual pumice and ash falls and to make definite correlation from one location to another. Five sample locations were chosen because the ash layers were definite and easily distinguishable (Plate 1, sample locations A to E). Figure 21 shows the two layers found at sample location C.

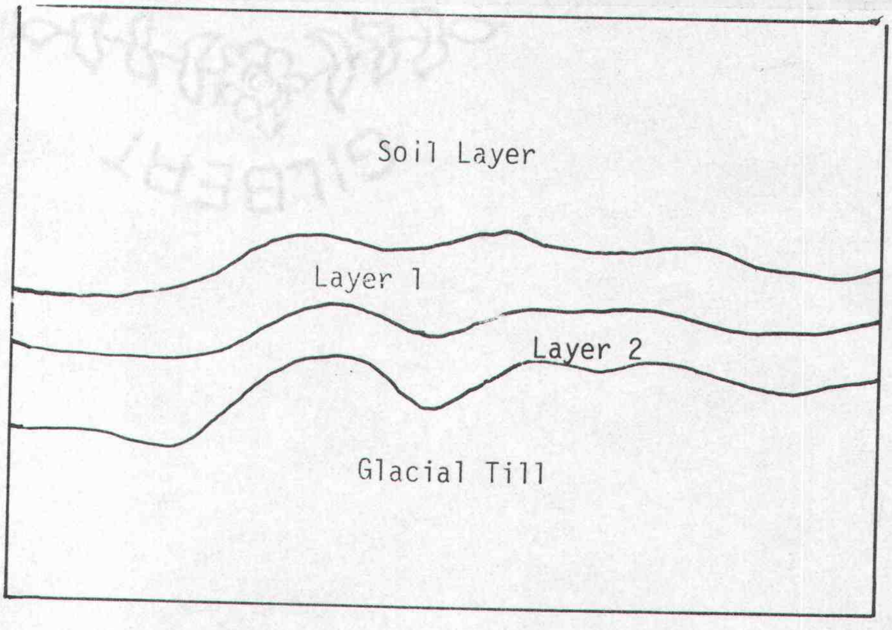


Figure 21. Two layers of airfall pyroclastic debris: undulatory contacts and varying thickness are common features. Gray layers are due to organic effects on the airfall deposits. (Location 17, Appendix 3).

Older Layer

The older layer is two to four inches thick at sample locations A and C. It is composed of 40 percent very coarse, sand-sized ash and 60 percent pumice lapilli averaging two millimeters, with the largest five millimeters in diameter. The smaller grains were concentrated at the bottom of the layer. Weathered rinds on all fragments give a moderate yellowish brown (10YR5/4) color to the layer, but when the larger lapilli are broken, a very pale orange (10YR8/2) is seen. Euhedral plagioclase and hornblende phenocrysts are present in the larger lapilli. Petrographic and chemical studies were not attempted because of the weathered condition of this layer.

Younger Layer

The younger layer is present at all five sample locations. It is composed of 30 percent coarse ash, .5 to 4 millimeters, and 70 percent pumice lapilli averaging five millimeters, with some fragments nine millimeters in diameter. Reverse size-grading is present at several locations, and is probably due to the low density of the lapilli that caused them to settle to earth after the denser ash. Euhedral, normally zoned, feldspar crystals less than one millimeter in diameter are the predominent phenocrysts in the lapilli. Dark black, prisms of hornblende, 0.5 to 1 millimeter long and green cummingtonite crystals less than 0.5 millimeters long are also present, and show perfect amphibole cleavage.

The lapilli were studied petrographically, and amphibole phenocrysts were separated by hand and studied by x-ray diffraction.

Age and Correlation

The small size of the fragments and the modest thickness of layers indicate that Mount Adams is not the source for these deposits. The younger layer is tentatively correlated with ash layer Y from Mount St. Helens. Layer Y, described in the Mount Rainier area, is similar in physical characteristics. It is the only layer of several found near Mount Rainier in which pyroxene is rare. From radio-carbon age dating of organic debris within and below the layer, it is believed to be 3200 years old (Crandell and others, 1965). Cummingtonite, plagioclase, and hornblende are the primary phenocrysts recognized by Hyde (1970) near Mount St. Helens. Hyde also indicated the distribution of layer Y would include the Mount Adams area.

The older layer could be J or S as described by Hyde (1970), but this deduction is based almost entirely on the layer's position in relation to the younger layer. The weathered condition of the older layer makes adequate mineral identification and sample description impossible. Also, locations for sampling are sparse so correlation of the layer is not possible.

To correlate the two layers of the Babyshoe Ridge area positively with pumice layers described elsewhere in the Cascades, is not within the scope of this thesis. The regional distribution of the airfall deposits, neutron activation analysis, and titanium oxide comparisons are suggested as possibilities for future studies.

HYDROTHERMAL ALTERATION

Two zones of hydrothermal alteration were found in the thesis area. The largest zone, A, is approximately one mile wide and two miles long, crudely rectangular, and lies in the central part of the area. Zone B is less than one-quarter of a square mile in area, roughly circular in shape, and located near Table Mountain (Plate 1).

Zone A

The hydrothermal alteration of Zone A is confined to the Council Bluff unit. Mount Adams lavas that partially overlie the altered Council Bluff rocks are uneffected. U. S. Forest Service road # N84 has the best exposures of altered rocks in Zone A in its road cuts. Highly altered andesite mudflows and lava flows display obvious physical changes such as bleaching and softening. Although weathering has similar effects on flow rocks, it can be distinguished from hydrothermal alteration, because it changes only the surface of outcrops. Weathering forms rinds of less than four inches thick whereas hydrothermal alteration penetrates to the core of large boulders.

The Council Lake fault, associated smaller faults, and vertical jointing are the major factors locating alteration zone A. The Council Lake fault intersects the western margin of the zone. Fractures in nearby rocks and the gouge zone, caused by movement along this fault, show intense alteration in the form of red to bluish-gray clays. Vertical jointing which was responsible for channeling altering fluids are visible in the gravel pit on Babyshoe Ridge. Figure 22 shows a progressive sequence of alteration in rocks taken from this pit.

Characteristic alteration minerals are chlorite, kaolinite, sericite, pyrite, quartz, and calcite. Chlorite commonly gives a greenish tint to the altered rocks, and occurs primarily as an alteration product of pyroxene crystals in phenocrysts and the groundmasses of flow rocks. Kaolinite and sericite usually occur in intensely altered zones along fractures, and are associated with pyrite. Figure 23 shows a quartz veinlet, associated bleaching, and calcite from altering plagioclase.

Zone B

The hydrothermal alteration of zone B can be seen along Boulder Creek near Table Mountain (Plate 1). Dark basaltic andesites, andesites, and volcanic clastic rocks have been bleached to a light gray color and mineralized with pyrite. Quartz veinlets are common, averaging less than one inch thick. Sample # 37-73 (Location 19, Appendix 3) is an example of this alteration. The sample is a Council Bluff andesite that shows ghosts of plagioclase glomerocrysts completely altered to calcite. Magnetite has been oxidized to hematite. The groundmass has been altered to kaolinite, quartz, and possibly other clay minerals. Quartz cavity fillings make up the rock, and are lined with pyrite and calcite.

Figure 22. Altered rocks: sequence from left to right of increasingly altered rocks from Location 18. Appendix 3. The black glassy andesite shows bleaching along platy jointing.

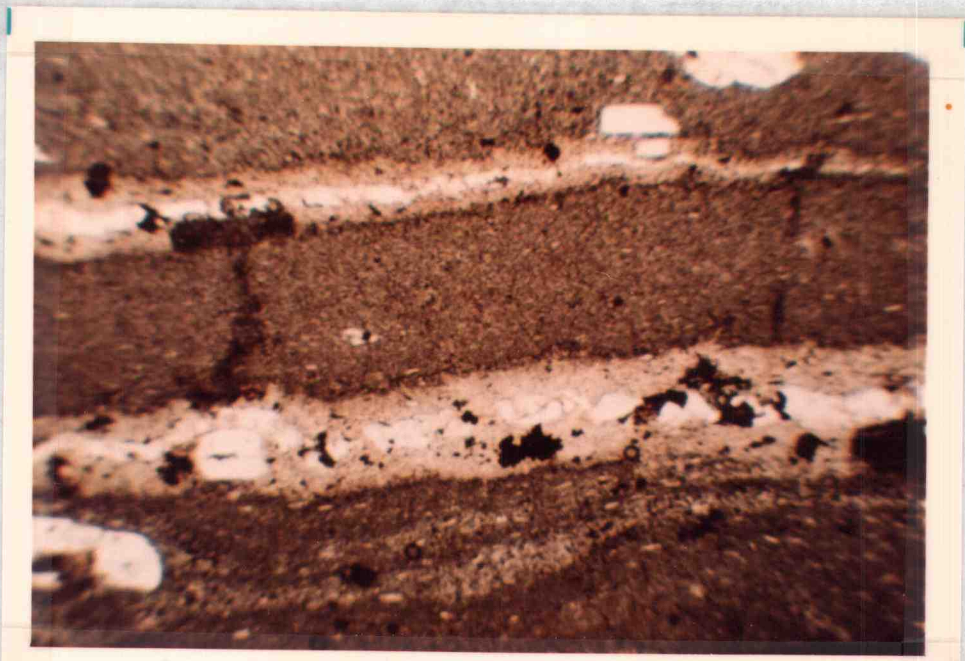


Figure 23. Photomicrograph of alteration and bleaching along veinlet of quartz.

The volcanic center of Table Mountain is believed to be instrumental in producing the hydrothermal fluids for zone B. The fluids were probably a mixture of magmatic waters and surface waters set in motion by heat from the magma chamber.

Discussion

The characteristic mineral assemblages are similar in both zones, and are possibly genetically related. They were formed in the same rock unit sometime after the deposition of the Council Bluff unit, and definitely before deposition of Mount Adams lavas.

Comparative chemical analyses and trace element analyses of altered and unaltered rocks are summarized in Table 1. Important inferences from the data are:

1. The error in total oxide percentages of samples # 37-73 and # 38-73 seems to be excessive. Thin sections of these samples show calcite and pyrite in significant amounts. The fusion method employed in obtaining "whole rock" chemical analyses requires the powdered samples to be heated to 1100° C, which is sufficient to drive off SO_2 and CO_2 gases.
2. Altered rocks show trace element values that are very near the background values established by the analyses of unaltered rocks. Molybdenum, which tested less than one part per million, showed no increase, and is the least likely to be mobilized by leaching if enrichment had taken place (Titley, 1963).

Table 1. Chemical comparison of altered and unaltered rocks.

	UNALTERED		ALTERED	
Sample #	39-73	D-3	37-73	38-73
SiO_2	56.3	60.3	54.4	53.0
Al_2O_3	17.7	17.4	17.2	17.0
FeO	8.9	7.0	7.9	7.1
MgO	4.2	1.6	2.6	3.4
CaO	7.8	5.8	7.1	8.9
Na_2O	3.1	4.2	3.2	1.8
K_2O	1.06	1.68	1.17	0.74
TiO_2	1.89	0.79	0.87	0.86
	99.95	98.77	94.44	92.8

Trace element analysis in PPM

Pb	10	10	10	10
Zn	70	55	100	80
Cu	90	25	60	40
Mo	-1	-1	-1	-1

A minus sign is to be read "less than"

This decreases the possibility that copper, lead, and zinc were once deposited and then removed.

3. The percentage of SiO_2 is lower in the altered samples. This could be due to the removal of silica by hydrothermal fluids. Another possibility is that the lower percentage is only apparent, and due to the volatiles driven off during analysis. Since calcite and pyrite were added to the rock, their pressure would lower the percentages of all oxides. The most abundant elements would be effected the most.

STRUCTURE

Principal features of structural geology in the area include broad folds, a homocline, and faults.

Homocline

The most obvious structure in the area is the homocline, indicated by the attitude of the East Canyon unit. The beds in the homocline have an average attitude of N. 50° W., 30° SW, but the strike varies from N. 45° W. to N. 55° W., and the dip from 31° SW to 24°SW. Dip slopes are common topographic manifestations of well-bedded, resistant sandstone units of the East Canyon unit, and crude flatirons are formed by these beds on the north wall of East Canyon.

Folds

Most of the outcrops of the Council Bluff unit are massive, and attitudes are difficult to measure. The few attitudes measured agree with the folds as interpreted below, but are insufficient to define them.

Two broad folds are inferred in the Council Bluff unit: Table Mountain anticline and Boulder Creek syncline. Their axes are arcuate, convex to the northeast, and trend approximately N. 45° W., plunging 10° SE under the Mount Adams lavas. The southern limb of the Table Mountain anticline is described by a sequence of 10 to 30 feet thick lava flows dipping eight to nine degrees southeast

(Figure 6). Along Boulder Creek, mudflows and lava flows make up the limb shared by the Boulder Creek syncline and Table Mountain anticline. The south slope of Council Bluff is the northern limb of the syncline (Plate 1).

Faults

The major fault in the area, Council Bluff, is north-south trending, and extends north from the Lewis River through Council Lake an unknown distance beyond the area. It is an almost vertical fault, but it is possible that the fault plane dips steeply to the east. ERTS imagery helps to reveal the fault by showing a regional lineation (Figure 12). Displacement has been vertical, at least 400 feet, and is exhibited by the truncation of the eastern end of East Canyon Ridge which is the upthrown block (E1/2, Sec. 2, T. 9 N., R. 9 E. Appendix 3). Erosion could have altered the scarp so the amount of displacement is uncertain. A parallel fault, to the west of the main fault, shows less displacement and lateral extent. Other smaller slump faults can be seen in road cuts, but no additional regional trends were noted.

GEOLOGIC HISTORY

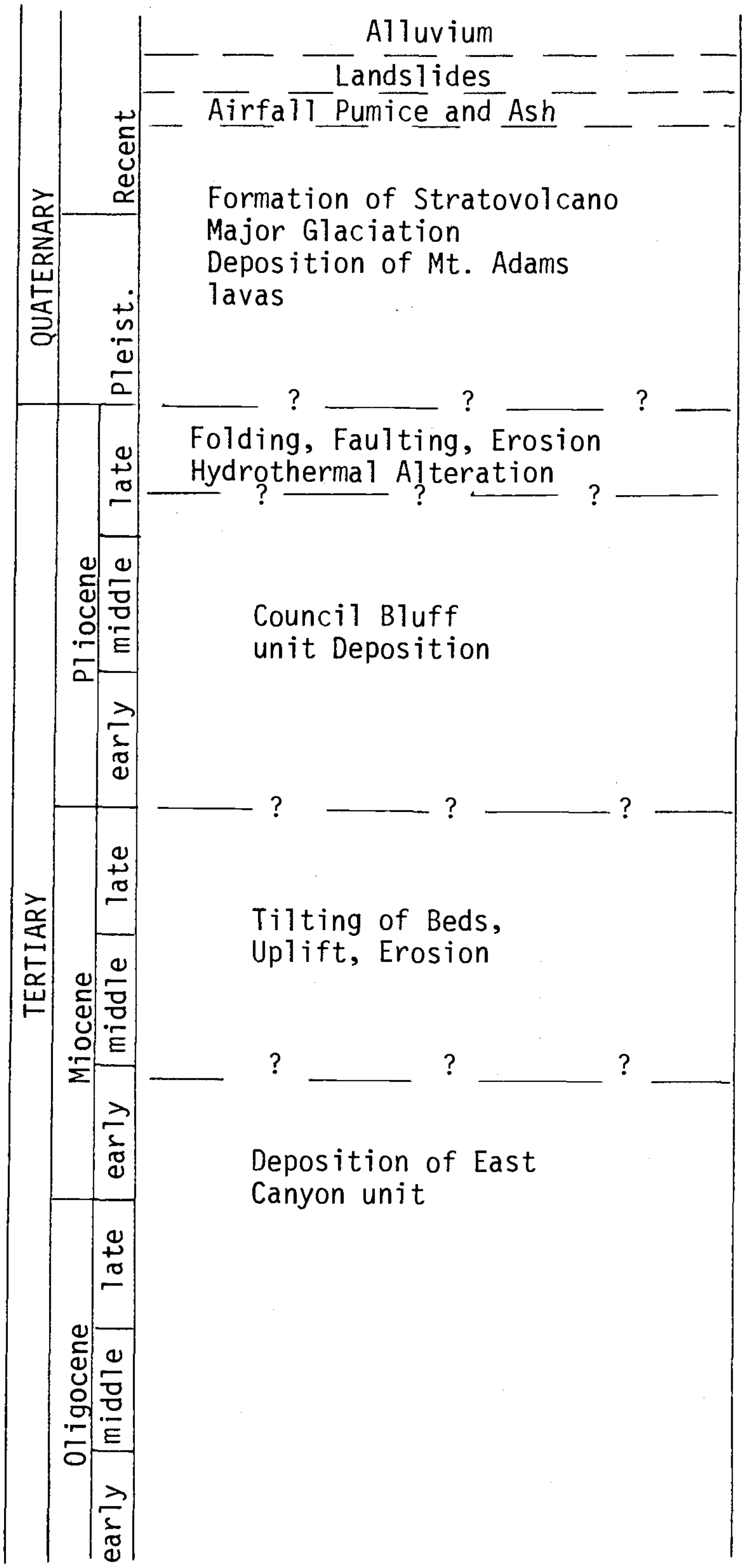
The history of volcanism, sedimentation, and deformation, as recorded in the rocks of the Babyshoe Ridge area, is summarized in Plate 4.

The oldest exposed rocks of the Babyshoe Ridge area show that by early Oligocene the central Cascades region was occupied by a continental trough which was intermittently filled with water. A large amount of pyroclastic debris, mostly andesitic to dacitic in composition, was deposited by explosive volcanoes within the region. Pyroclastic flows were deposited on a rough terrain created by a rapidly accumulating volcanic pile, probably undergoing some deformation. Accumulations of reworked pyroclastic debris were interspersed between the flows, and became more common as this time of volcanism subsided. Volcanic sandstones and thick-bedded siltstones containing large fir trees were deposited from a source area to the east. These rocks are called the East Canyon unit in this thesis.

A time of tilting and erosion of the East Canyon unit came before the deposition of the Council Bluff unit. Although difficult to determine from the rocks of Babyshoe Ridge area, a broad synclinal basin was probably formed that later became the site of deposition for volcanic debris.

By Pliocene time, basaltic andesite and andesite had begun erupting into the basin from several volcanic sources. Council Bluff shows cross-bedding in mudflows that indicate a source

Plate 4. Columnar summary of geologic history of Babyshoe Ridge area.



to the east. Table Mountain could have been a volcanic center for many of the flows in that area.

During or near the end of the eruptions of Council Bluff volcanics, folding and major faulting took place. The two subtle folds trending northwest confirm roughly to the deformational trends exhibited by the East Canyon unit which now forms a homocline.

> Tertiary folding, faulting, uplift, and downwarping occurred along northwesterly trends. Beginning in probable middle Pliocene time epierogenic upwarping took place along a north-south axis. This 40° divergence from early patterns of stress may have helped locate Pliocene-Pleistocene andesitic volcanism. (Grant, 1969, p. 39).

The north-south trending Council Lake fault formed a prominent scarp on the eastern end of East Canyon Ridge that was 200 to 400 feet high. Erosion also was important in carving the topography in preparation for the deposition of the lavas that make up the Mount Adams volcano.

Alteration along the Council Lake fault probably occurred near the beginning of Pleistocene volcanism. Since none of the Mount Adams lavas are altered, the alteration occurred prior to their deposition.

During Pleistocene time, the andesites of Mount Adams were deposited on terrain with relief of up to 100 feet. Compound and simple flows emanated from flank fissures to the southeast of Babyshoe Ridge. Glaciated valleys and the fault scarp determined the limits of the flows that took on a primary dip of approximately 5° to 15° NW. Glacial deposits from at least two glacial periods are described in the previous section on Glacial History.

The Recent geologic record shows two pyroclastic airfall deposits spread over the area in sheets of four to six inches thick. The probable source is Mount St. Helens. Recent landslides have occurred in the past, and one is still active in the southwest corner of the area.

GEOTHERMAL POTENTIAL

Preliminary reconnaisance revealed evidence in favor of this area furnishing geothermal resource: 1) The area is near a volcanic center (Mount Adams) that was active in Recent times. 2) A major vertical fault is located in the area (Council Lake fault). 3) The area has a large alteration zone (zone A) that appears to be the result of a hydrothermal system. However, further field and laboratory investigation in this thesis indicate geothermal potential is lower than previously believed.

Genetic Relationships

I believe that a hydrothermal system with probable geothermal potential produced alteration zone A, but that the system was active in approximately late-Pliocene time, and now has little potential. The following discussion describes the genetic relationships of several important factors related to geothermal potential.

The zone A alteration is believed to be genetically related to the Council Lake fault. The fault was probably instrumental in transporting heated water to a reservoir at shallow depth, or it could have been responsible for allowing hot magma to approach the surface to heat ground waters. The resulting hydrothermal fluids carrying dissolved silica and other elements, then could have penetrated rocks of the Council Bluff unit along small fractures and joints produced by regional stresses. At this time of faulting and deformation, late-Pliocene, silicification could have formed an impermeable cap sealing off the hydrothermal system from the surface.

The volcanism that produced the Mount Adams lavas is definitely younger than the Council Lake fault and the period of alteration as shown by: 1) The Mount Adams lavas overlie alteration zone A and are unaltered. 2) The Olallie Lake andesite was restricted by the scarp of the Council Lake fault when it was deposited.

Recommendations

The Babyshoe Ridge area does not appear at this time to be a good geothermal prospect. It must be remembered, however, that the conclusions in this thesis have been based on limited field and laboratory studies. A structural, stratigraphic, and petrologic model has been developed in this thesis, but a hydrologic model is still lacking. The area has many cold, fresh water springs, and several springs which contain iron oxides, that should be systematically sampled and tested. If chemical analyses of spring water reveal anomalous element percentages the possibility of a presently active hydrothermal system exists. Geophysical surveys would then be appropriate to further determine the geothermal potential.

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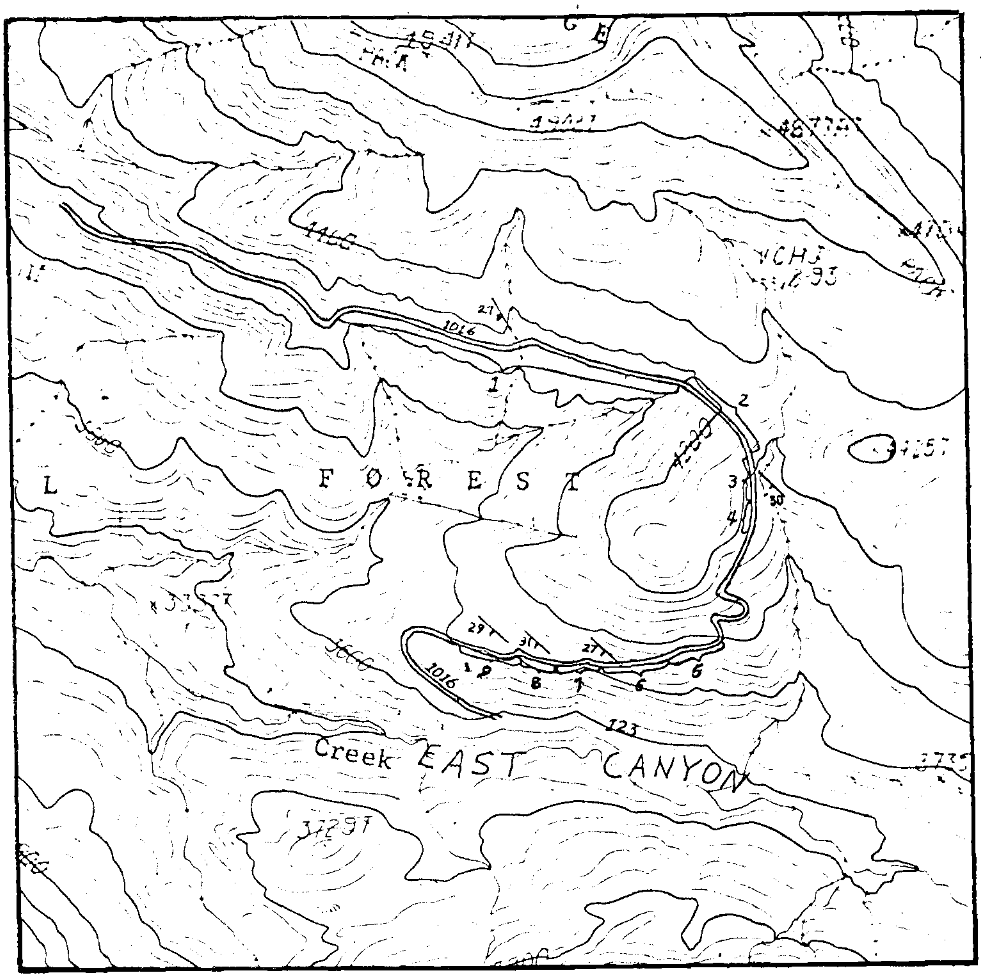
APPENDICES

APPENDIX I

Measured section, Stevens Ridge Formation; measured on north side of East Canyon, along road 1016, SE1/4, Sec. 2, T.9N, R.9 E. Thicknesses of units are approximate and taken from map and outcrop estimates. Location of section measurement is plotted on the map insert below:



UNIT	LITHOLOGIC DESCRIPTION	THICKNESS	TOTAL
9	Sandstones and siltstones: a series of well-bedded, non-resistant rocks; greenish gray (5GY6/1), weathering to yellowish gray (5Y7/2); beds range 1"-2', averaging 6" thick; sandstones are more strongly indurated than the siltstones and are more resistant to erosion; good to fair sorting; angular to subangular;	60'	955'

load casts visible; some very coarse sandstones have zeolites filling interstices; beds become thicker toward base of unit.

Contact: covered

8 Volcanic sandstones, siltstones, and breccias: 60' 895'
a series of well-bedded moderately resistant rocks; greenish gray (5GY6/1), weathering to light brown (5Y7/2); beds vary 1"-4', averaging 1' thick; normal grading visible in some beds; commonly very coarse sandstones grade upwards into siltstones; some sandstones show good sorting and angular fragments; most rocks are well indurated; flattered pumice fragments visible in some breccias; all beds are highly pumiceous; breccias have a disrupted framework of pumice and andesite fragments (1/4"-1"), composing from 20% to 80% of the rock.

Contact: covered

7 Volcanic sandstones, siltstones, and breccias: 60' 835'
a series of well-bedded pumiceous deposits; yellowish gray (5Y8/1), weathering to grayish orange (10YR7/4); beds vary 1"-4'; spheroidal weathering common; moderately indurated; friable when weathered; breccia is the predominant rock type (70%) with disrupted framework (40%) of angular, randomly oriented, red and gray andesite fragments and white pumice fragments, ranging from 1/4" to 1", fair sorting; breccia matrix (60%) is devitrifying pumice and volcanic ash forming a light gray (N7) clay.

Contact: covered

6 Pyroclastic flow: very light gray (N8), 30' 775'
weathering to yellowish gray (5Y8/1); well/indurated, forming an erosion resistant unit; two prominent planar joint sets at 90° to one another; distrupted framework (30%) composed of angular pumice and glassy andesitic fragments (1/8"-1"), most fragments show devitrification; matrix (70%) is highly pumiceous, contains 5% quartz and plagioclase crystals, showing euhedral to subhedral form.

Contact: covered

5	Pyroclastic flow: light brownish gray (5YR6/1), weathering to light olive brown (5Y5/6); moderately indurated, locally highly fractured and weathered; massively bedded (up to 20'); disrupted framework (50%) composed of angular pumice and light gray (N7) andesite fragments (1/2"-1"), poor sorting, localized stretching and flattening of pumice fragments due to compaction, devitrification is prevalent; matrix (50%) composed of devitrified pumice and glassy andesite particles of sand and smaller size, quartz (5%) and plagioclase (3%) crystals that are euhedral to subhedral.	60'	745'
	Contact: covered		
	Covered interval	500'	685'
	Contact: covered		
4	Volcanic siltstones and sandstones light brown (5YR6/4), weathering to pale yellowish brown (10YR6/2); beds vary 1"-10", averaging 6" thick; moderately indurated; normal particle size grading in 4-6" thick sandstone beds; poor sorting; angular to subangular fragments; euhedral plagioclase and quartz crystals are visible in most beds; pumice is a primary constituent.	30'	185'
	Contact: conformable, sharp		
3	Pyroclastic flow: pale blue green (5BG7/2) weathering to light brown (5YR6/4); planar jointing prominent in one direction; outcrop commonly shows spheroidal weathering; disrupted framework (40%) composed of pumice and andesitic fragments (1/4"-1"), rare 4" fragment, orientation and elongation of fragments; matrix (60%) mostly clay from devitrified pumice and ash with quartz and plagioclase crystals (10%) in euhedral to anhedral forms.	25'	155'
	Contact: covered		

2	Volcanic sandstones and siltstones: a series of well-bedded, undeformed sedimentary rocks; fresh and weathered rock colors range from pale yellowish brown (10YR6/2) to black (N1) depending on the amount of carbonaceous material; beds vary 1"-2', averaging 1' thick; most rocks are well endurated; moderately resistant to erosion; sandstone beds 4-6" thick show normal particle size grading and many grade into siltstones; most sandstones are wackes with angular clasts; pumice is a primary constituent. Contact: covered	30'	130'
1	Volcanic sandstones, siltstones, and mudstones: a series of well-bedded, undeformed sedimentary rocks; greenish gray (5GY6/1), weathering to dark greenish gray (5GY4/1); beds vary 2"-4', averaging 1' thick; most beds are well-indurated; normal grading is evident with sandstones commonly grading upwards into mudstones; sandstones show fair sorting and angular grains; contains fossil trees that have been partially silicified, with associated fossil fir needles. Contact: covered	100'	100'

APPENDIX II

Chemical Analyses of Airfall Pumice.

Oxide	B-1	D-1	Mazama 1	Mazama 2
SiO_2	64.3	65.3	72.65	70.80
Al_2O_3	19.1	18.6	13.22	15.05
FeO	3.8	3.9	2.58	2.67
MgO	1.0	0.8	0.89	0.55
CaO	4.6	4.4	1.49	2.40
Na_2O	4.7	4.7	Not determined	5.70
K_2O	1.20	1.24		2.77
TiO_2	0.37	0.44		0.54
	99.07	99.58		99.97

B-1 Airfall pumice Location B (Plate 1)

D-1 Airfall pumice Location D (Plate 1)

Mazama 1 - Lindstrom (1972) Coarse airfall dacite pumice

Mazama 1 - Lindstrom (1972) Pumice from Pinnacles, Crater Lake, National Park

Chemical Analyses of Mount Adams lavas

Oxide	D-26	D-10	M-963	*West Cascades Oregon
SiO_2	66.6	58.7	58.7	60.7
Al_2O_3	16.0	16.5	16.5	16.6
FeO	4.9	7.5	7.4	7.5
MgO	0.4	2.2	2.2	2.9
CaO	2.8	6.1	6.1	5.6
Na_2O	5.5	4.4	4.5	3.9
K_2O	3.22	2.1	2.15	1.5
TiO_2	0.65	1.34	1.28	1.0
	100.07	98.84	98.83	99.7

D-26 - Olallie Lake flow, along USFS Rd. # 123 near Olallie Lake. (Appendix 3, Location 14)

D-10 - Takhlakh Lake flow, along USFS Rd. # N84 near Big Spring Creek (Appendix 3, Location 20).

M-963- Takhlakh Lake flow, along USFS Rd. # 101, at Tach Tach Meadow (Appendix 3, Location 12)

*Peck and others, 1964, average of 30 samples.

Modal Analyses (500 point count)

Mineral	D-26	D-10	M-963
Plagioclase	5.4	24.0	18.0
Clinopyroxene	1.4	4.6	3.4
Orthopyroxene	-	1.8	1.6
Magnetite	.6	.2	1.6
Groundmass**	92.6	69.4	58.4
Voids	-	-	17.0
	100	100	100

**Groundmass - Microcrystalline plagroclase, pyroxene, magnetite, volcanic glass.

Chemical Analysis of Council Bluff unit

Oxide	D-3	39-73	27-73	*West Cascades, Oregon
SiO_2	60.3	56.3	58.9	60.7
Al_2O_3	17.4	17.7	16.6	16.6
FeO	7.0	8.9	7.9	7.5
MgO	1.6	4.2	2.0	2.9
CaO	5.8	7.8	6.6	5.6
Na_2O	4.2	3.1	4.0	3.9
K_2O	1.68	1.06	1.60	1.5
TiO_2	0.79	0.89	1.12	1.0
	98.77	99.95	98.72	99.7

D-3 Flow from Table Mountain near Twin Falls campground. (Appendix 3, Location 21)

39-73 Flow from Table Mountain along Boulder Creek (Appendix 3, Location 5)

27-73 Flow along USFS Rd. # N925 near headwaters of Boulder Creek (Appendix 3, Location 13)

* Peck and others, 1964, average of 30 samples.

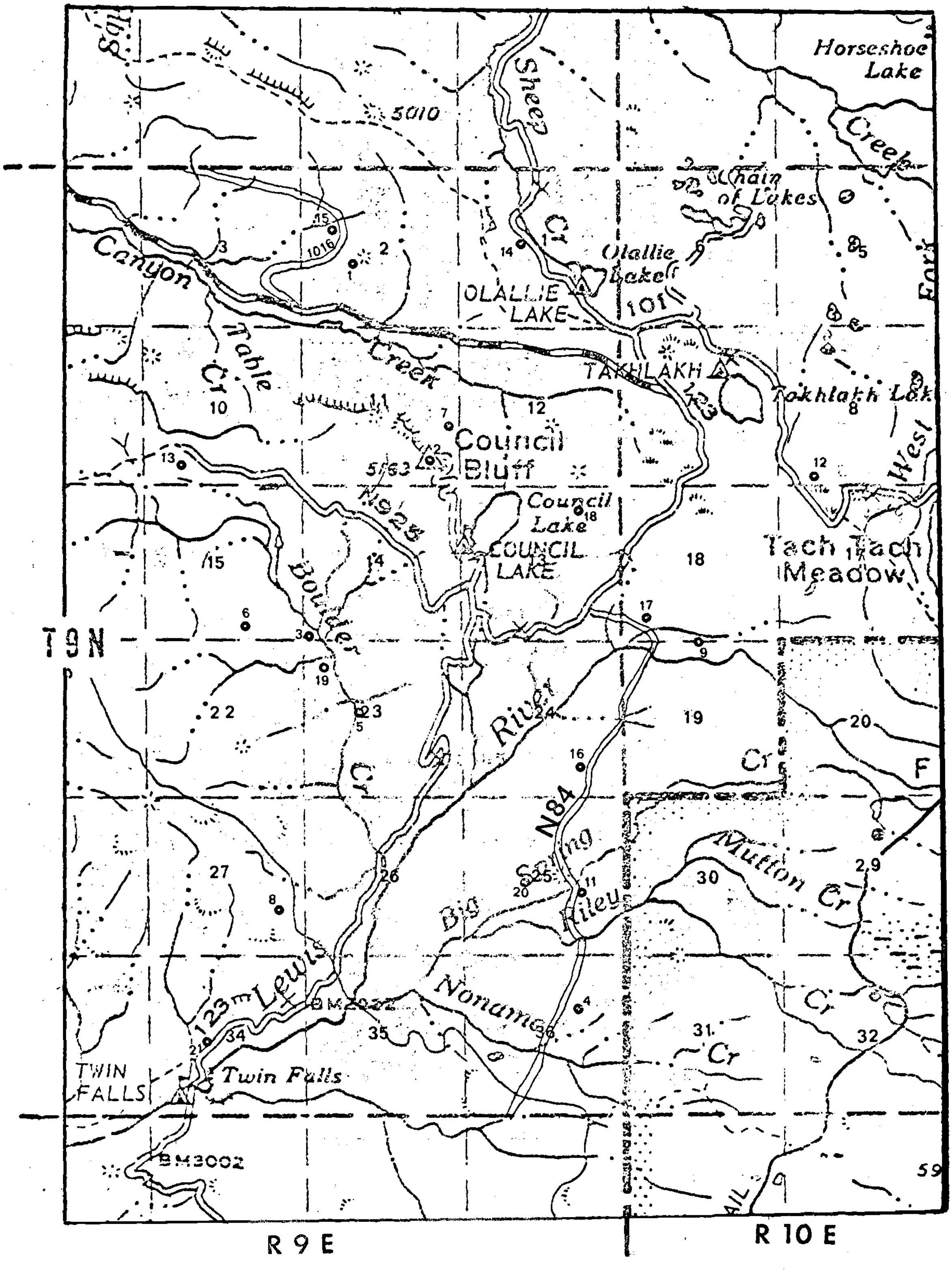
Modal Analyses (500 point count)

Mineral	D-3	39-73	27-73
Plagioclase	16.8	25.8	13.4
Clinopyroxene	3.4	4.2	4.8
Orthopyroxene		2.2	
Magnetite	.8	.6	.6
Groundmass**	79.0	67.2	78.6
	100	100	100

** Groundmass - microcrystalline plagioclase, pyroxene, magnetite, volcanic glass.

APPENDIX III

LOCATION MAP FOR SAMPLES AND PHOTOGRAPHS



Location Number	Description	Grid Coordinates
1	Figure 2	NE 1/4, SW 1/4, Sec. 2, T.9N., R.9E.
2	Figure 4, viewpoint	SE 1/4, SE 1/4, Sec. 11, T.9N., R.9E.
3	Figure 5	SW 1/4, SW 1/4, Sec. 14, T.9N., R.9E.
4	Figure 6, viewpoint	SW 1/4, NE 1/4, Sec. 36, T.9N., R.9E.
5	Samples 39-73	SE 1/4, NW 1/4, Sec. 23, T.9N., R.9E.
6	Sample D-20, 6-73a	SW 1/4, SE 1/4, Sec. 15, T.9N., R.9E.
7	Sample 31-73	NE 1/4, SE 1/4, Sec. 11, T.9N., R.9E.
8	Figure 10	NE 1/4, SE 1/4, Sec. 27, T.9N., R.9E.
9	Outcrop Location	SW 1/4, SE 1/4, Sec. 18, T.9N., R.9E.
10	Figure 14	Same as location B 12
11	Figure 15	NW 1/4, SE 1/4, Sec. 25, T.9N., R.9E.
12	Sample M-963	SW 1/4, SW 1/4, Sec. 8, T.9N., R.10E.
13	Sample 27-73	SW 1/4, SW 1/4, Sec. 10, T.9N., R.9E.
14	Sample D-26	SE 1/4, NW 1/4, Sec. 1, T.9N., R.9E.
15	Figure 19	SW 1/4, NW 1/4, Sec. 2, T.9N., R.9E.
16	Figure 20	SW 1/4, SE 1/4, Sec. 24, T.9N., R.9E.
17	Figure 21	SW 1/4, SW 1/4, Sec. 18, T.9N., R.10E.
18	Figure 22, 23	NE 1/4, NE 1/4, Sec. 13, T.9N., R.9E.
19	Sample 37-73	SW 1/4, NW 1/4, Sec. 23, T.9N., R.9E.
20	Sample D-10	NE 1/4, Sw 1/4, Sec. 25, T.9N., R.9E.
21	Sample D-3	NE 1/4, SW 1/4, Sec. 34, T.9N., R.9E.