

1980

Geology of the southcentral margin of the Tillamook Highlands; southwest quarter of the Enright Quadrangle, Tillamook County, Oregon

Kenneth Allan Cameron
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<https://doi.org/10.15760/etd.3189>

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AN ABSTRACT OF THE THESIS OF Kenneth Allan Cameron for the Master of Science in Geology presented May 7, 1980.

Title: Geology of the Southcentral Margin of the Tillamook Highlands; Southwest Quarter of the Enright Quadrangle, Tillamook County, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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Paul E. Hammond

The Tillamook Highlands is a largely unmapped volcanic pile located in the north end of the Coast Range of Oregon. The 36 square miles of T. 1 N., R. 8 W., on the southcentral margin of the Highlands, was chosen for detailed study.

The study area is composed of Eocene age sedimentary and volcanic units which were deposited in a filling basin. The lowest units were deposited in moderate to deep marine waters; the uppermost were deposited subaerially.

Stratigraphically lowest is a unit composed of 800 meters of

rhythmically bedded, poorly indurated, sparsely fossiliferous, brown siltstone with rare interbeds of volcanic lithic sandstone. On the basis of fossil evidence (the pelecypods Glycimeris sp. and Acila sp.), it is believed that this material was deposited in moderate to deep marine water.

Conformably overlying the siltstone is 900 meters of submarine volcanoclastic deposits with minor sedimentary sub-units and a large tuff lens. The major rock type is a zeolite cemented flow breccia. Minor amounts of pillow lavas and hyaloclastites are found in the upper one-third of the unit. The sedimentary sub-units, consisting of immature volcanic feldspathic litharenites and tuffaceous shales, have a total thickness of 35 meters. The shales are very fossiliferous, containing remains deposited in shallow water of the plants Cornus sp. (dogwood), Picea sp. (spruce), Chamaecyparis sp. (cedar) and Ailanthus sp. (Tree of Heaven). These plants show that a warm temperate climate existed in this area during the Eocene. The tuff lens is a deposit of water-worked crystal-vitric tuff. It has a maximum thickness of 100 meters and an areal extent of over one square kilometer. It is characterized by an abundance of large (up to 3 centimeters) euhedral clinopyroxene crystals.

Conformably overlying the volcanoclastic unit is at least 900 meters of subaerial pyroxene basalt in the form of individual flows 20 to 30 meters thick. The basalt and volcanoclastic material interfinger for 100 meters at the contact. Major oxide analysis shows that these two units are chemically identical and are probably the product of the same parent magma. The differing habit of the units is the result of differing environments of deposition; the volcanoclastics are submarine

and the basalts subaerial. The contact represents sea level during the extrusive period.

A large diabasic sill has intruded the marine siltstones. It has a glassy chilled margin with rudimentary columnar jointing which grades into white or green diabase with an ophitic core. Total thickness of this unit exposed in the study area is 300 meters.

Structure is dominated by a regional dip of 18° to the northwest which is complicated by three generations of post-dip faulting. The first generation trends northwest, the second northeast, and the third east-west. All faults are vertical and show no strike-slip component.

Dikes with thicknesses over one meter are aligned, trending N30W. This is a result of the regional stress pattern at the time of intrusion, probably compressional stress with σ_1 oriented east-west.

GEOLOGY OF THE SOUTHCENTRAL MARGIN
OF THE
TILLAMOOK HIGHLANDS; SOUTHWEST QUARTER
OF THE
ENRIGHT QUADRANGLE, TILLAMOOK COUNTY, OREGON

by

KENNETH ALLAN CAMERON

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

MASTER OF SCIENCE
in
GEOLOGY

Portland State University

1980

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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ACKNOWLEDGMENTS

My deepest gratitude is extended to the faculty and students of the Earth Sciences department, Portland State University, and especially to Dr. R. Van Atta, my advisor, for their direct help and discussions of my project. Thanks go also to Northwest Explorations, Denver, and the Department of Geology and Mineral Industries, State of Oregon, for their financial assistance. Paleontological identification was greatly aided by the expertise of Susan Bee, Portland State University.

Lastly I would like to thank Ellen, my wife, for her patience, encouragement, and inspiration, and Puppy, our ancient pick-up that thinks it's a jeep.

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CHAPTER I

INTRODUCTION

STATEMENT OF PURPOSE

This study was undertaken with the purpose in mind to define, delineate, and map the units making up the southcentral margin of the Tillamook Highlands. This was accomplished through the study of the field relations, petrography, chemistry, and paleontology of the included lithosomes. It is also hoped that this study will serve as a starting place for additional researchers to continue work in this largely unknown part of the Coast Range.

PREFACE

The topography of the western margin of Oregon and Washington is dominated by a range of highly eroded hills known as the Coast Range. Near the center of the Coast Range, in the far northwest corner of Oregon, there is a relatively elevated, very rugged region known as the Tillamook Highlands. The area chosen for this study lies near the southcentral edge of the Tillamook Highlands, encompassing the entirety of T. 1 N., R. 8 W., in the southwest quarter of the Enright Quadrangle, Tillamook County, Oregon.

GEOGRAPHY

The study area consists of an upland region which contains the

headwaters of four major streams and over a dozen year-round creeks (see Figure 1). The main streams are the North Fork of the Kilchis River, which flows north out of the area; the South Fork of the Kilchis River, which flows northwest; the Little South Fork of the Kilchis River, which flows west; and the Little North Fork of the Wilson River, which flows south. The main fork of the Wilson River, the largest river in Tillamook County, flows through the southeast corner of the study area.

The highest elevations are on Cedar Butte, NE $\frac{1}{4}$, sec. 10, at 886 meters, and on Kilchis Lookout, NW $\frac{1}{4}$, sec. 17, at 808 meters (unless otherwise noted, all sections are in T. 1 N., R. 8 W.). The lowest point, 101 meters, occurs where the main fork of the Wilson River leaves the area in the SW $\frac{1}{4}$, sec. 36. The ridge walls are usually very steep, in some places deserving of the term "precipitous," with slope angles up to and greater than 45° . The canyon floors are narrow and generally choked with vegetation. Relief of 300 meters from ridge top to canyon floor is not uncommon.

Access to the area is good, especially in dry weather. The main highway from Portland to Tillamook, Oregon Highway 6, passes through the eastern edge of the area. Logging roads give initial access to the bulk of the area from Jordan Creek and Cedar Creek (see Figure 1). Once within the body of the study area, a veritable maze of existing and abandoned Oregon State Forest Service roads gives reasonable access by foot and vehicle to most parts of the area. These roads do, however, have a tendency to keep to the ridge tops, descending the valley walls only to cross the creek at the bottom and ascend back to the opposite ridge crest. They are graded dirt, usually driveable with the average

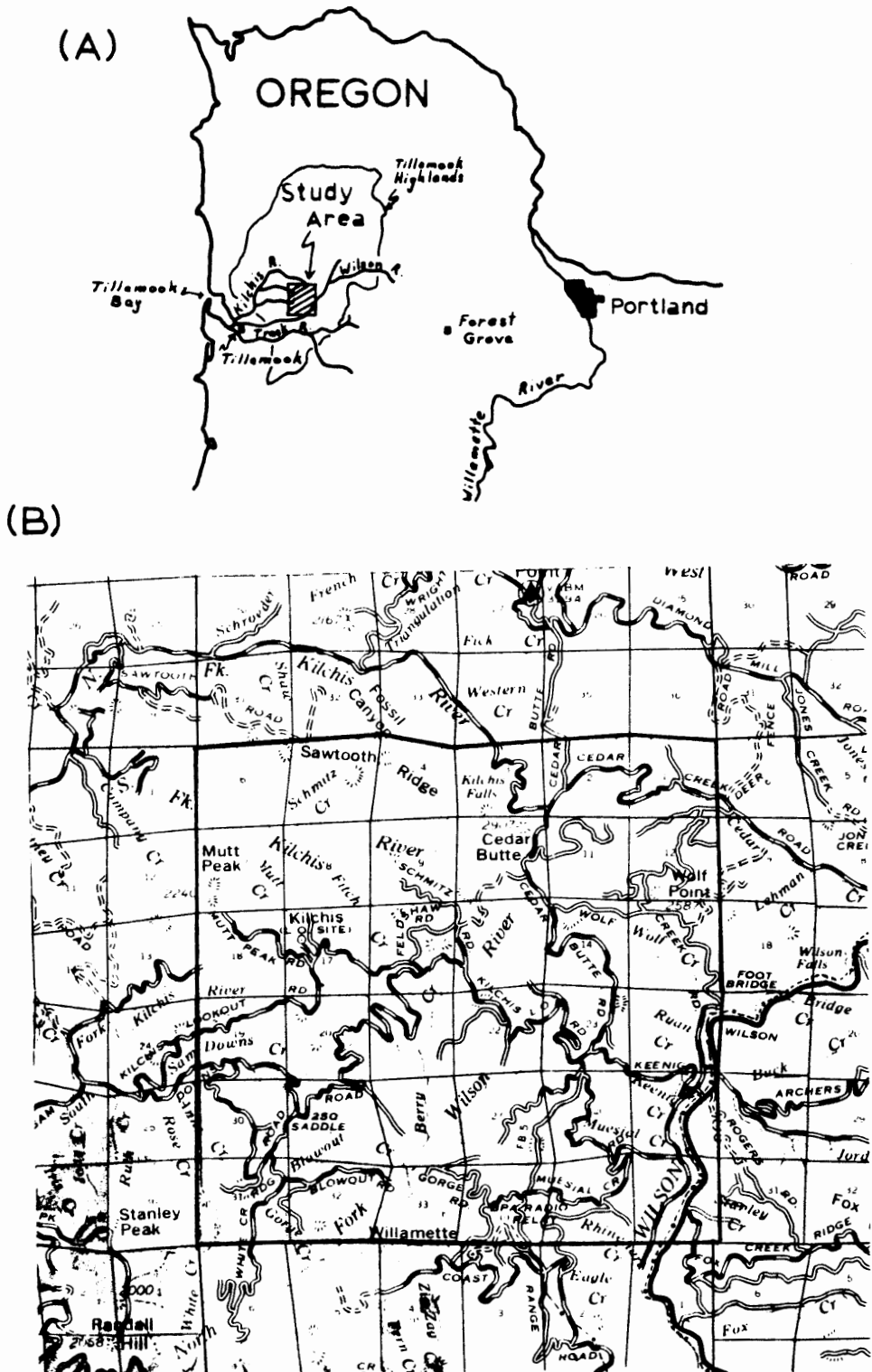


Figure 1. Location map (A) and political map (B) of the study area. All topographic names used in this report are from map B.

pick-up truck except in the wettest weather.

Except for Jordan Creek (a restaurant), Lee's Camp, and Glenwood (both of which are combination gas station - grocery stores), the nearest population centers are Tillamook, 25 kilometers to the southwest, and Forest Grove, 50 kilometers to the east.

ENVIRONMENTAL CONDITIONS

Climate

The one environmental factor which dominates conditions in the Tillamook Highlands, and the entire Coast Range, is rainfall. The Coast Range forms the first barrier to the storms driven off the Pacific Ocean by the prevailing westerly winds, forcing the clouds higher into the cooler regions of the atmosphere where they shed some of their moisture.

Annual precipitation totals near 250 centimeters are normal. During late fall and early spring it may rain continuously for weeks, not with great force but with astonishing persistence. Summers are mostly dry and warm (daily summer temperatures average from 16° to 25° C), but sea fogs which invade the ocean-facing valleys on most nights help keep temperatures down and humidity up. Winter snows first appear in November, but are interspersed with periods of rain and warmer temperatures (daily winter values average 0° to 10° C) which keep a winter-long snowpack from accumulating.

Plants

In botanical classification, the Tillamook Highlands are part of the North Coast - Humid Temperate zone. It is typified by thick stands of Douglas Fir, hemlock, and cedar with alder and maple inhabiting

stream banks and marshy areas. Open areas near water sport dense growths of fern, salmonberry and thimbleberry while drier ridge tops and slopes support huckleberry, blackberry, salal and tansy ragwort.

Animals

A record was kept of all native animals observed during the field work. Large mammals are represented by Roosevelt elk and white-tailed deer. Ravaged berry bushes and distinctive droppings indicate that black bear also inhabit the area. Very common vocally if not visually are family groups of coyotes. Examination of coyote scats for undigested hair, teeth, and bones indicates that, while unseen, not only deer and elk, but brush rabbits, mice and squirrels abound and fall prey to the carnivores.

The air teems with birds, the most common being various finches, sparrows and hummingbirds. These birds stay close to the thickest vegetation and are usually seen only as slashes of brown and grey among the branches. The evening air is filled, however, with the mixed choruses of their territorial songs. Among the larger, more conspicuous avian species are sparrow and redtailed hawks, vultures (which exhibit a depressing tendency to circle over the field worker throughout the day) and once, rising on the afternoon thermal currents created in the canyon of the South Fork of the Kilchis River, a great bald eagle.

Insects, though small, can have a tremendous impact on how fast and well field work is accomplished. The constant breezes which blow up the canyons during the day and down the canyons at night keep the ridges clear of most flying insects, especially the mosquito. The canyon floors where sheltered from these winds do give sanctuary to clouds of these

miniature vampires. Ticks, while not common, are sometimes found along the drier ridge crests. Ants, especially carpenter ants, are epidemic throughout the entire area and seem to be able to find their way into the most secure of tents.

HISTORY

The very name of this region, Tillamook, has roots embedded in the past. The Tillamook Indians were a tribe of the Salish linguistic group, united to the majority of this group in Washington and British Columbia by a common dependence on the dugout cedar canoe. Clans within the Tillamook tribe lived along the shore of Tillamook Bay and used the Tillamook Highlands as a hunting ground.

The largest river system within the study area takes its name from the last chief of the Tillamook tribe, Kilchis. Chief Kilchis was a large man of Negroid features and was probably a descendant of an African cabin boy lost on these shores by Captain Gray in the year 1788 (Orcutt, 1951).

The Wilson River system owes its name to Henry Wilson, who, in 1851, brought the first dairy cattle to the Tillamook Bay area (McArthur, 1974). This was the beginning of the milk products industry which has made Tillamook County the largest producer of cheese in the state.

More recently a series of events took place which directly influences the study of geology in the region. In 1933, 1939, and 1945 forest fires of unprecedented proportions swept the Tillamook Highlands, caused each time by improper logging practices. In all, over three

hundred square miles of old growth timber were destroyed. The thick stands of fir, hemlock and cedar were utterly obliterated by these fires, the burned area known collectively as the Tillamook Burn. The intense heat of the conflagrations sterilized the soil and with the coming of the winter rains it was swept from the hillsides and into the rivers, leaving behind ridges and hills of naked bedrock. The soil has started the slow process of regeneration, but it will be many decades before the hillsides are again covered with stately trees and the ridges with any vegetation at all. Until that time, geologists will find that field work here is easier than elsewhere in the Coast Range.

REGIONAL GEOLOGIC SETTING

The geologic history of the Coast Range is, at best, poorly understood. What is known is that during the early Tertiary a depositional basin extended from Vancouver Island in the north to the Klamath Mountains in the south and east to the present site of the Cascade Range (Snively and Wagner, 1963; Snively et al, 1980).

In early to middle Eocene time numerous centers of submarine volcanism on the floor of the basin erupted large quantities of basaltic pillow lavas and breccia (e.g., the Crescent Formation and Black Hills area of Washington and the Tillamook Highlands and Siletz and Roseburg volcanics of Oregon). This material interfingers complexly with marine sedimentary rocks (e.g., the McIntosh Formation of Washington) and terrigenous sandstones brought into the area by turbidity flows (e.g., the Tyee Formation of Oregon) which were being laid down continuously in the basin. By middle to upper Eocene time some of the submarine volcanoes had built up high enough to form islands of subaerial basalt

flows. The Black Hills of Washington and the Tillamook Highlands and the Siletz area of Oregon are probable island sites (Snively and Wagner, 1963).

Two models are currently in favor which try to explain the tectonic setting for the basin and its volcanics. The first holds that the material found in the study area was deposited on the ocean floor and "rafted" into the continent by an active subduction zone and spreading ridge (Dickenson, 1976). The material plugged the subduction zone, forcing the zone to jump to the west. This model would require that the volcanic material seen in the Coast Range is the product of oceanic magmas. The second model says that a subduction zone originally near the present site of the Cascade Range jumped to the west, stranding a piece of oceanic crust upon which was deposited the material seen in the study area. This model implies that the volcanic material is the product of magmas produced by subduction (Snively et al, 1980; Simpson and Cox, 1977).

Remnant magnetism studies of the volcanic material shows that in post Eocene time the entire Coast Range was rotated clockwise by 40° to 60° to its present location (Simpson and Cox, 1977).

FIELD WORK

Except for reconnaissance during the fall and winter of 1978, all field work was accomplished between the 25th of May and the 15th of September, 1979. An average week during this period consisted of three or four days of field work supported by one or two days of lab studies (thin section preparation or drafting). The Tillamook Highlands are a very popular location for off-road vehicle enthusiasts and it is not

safe to leave a campsite unattended while away doing field studies. This was a major consideration in not remaining in the field for longer periods of time. The majority of the field work was done without the aid of a field assistant.

Due to the paucity of soil cover along the ridge crests, most of the mapping was done by walking out and examining the ridges and extrapolating across the intervening canyons. What soil exists along the ridge walls is very thin, making road cuts another valuable source of lithologic data. The canyon floors of major streams and creeks were avoided for the most part because of extensive vegetation and stream laid deposits. Smaller side and intermittent streams located higher on the canyon walls often flow over bedrock and were used wherever possible.

Mapping commenced in the northeast quarter of the study area where a limited amount of mapping had been done previously (Nelson and Shearer, 1969) and proceeded south and west, concluding in the southwest corner. Field work was greatly aided, especially in the Sawtooth Range of sections 4, 5, and 6 (see Figure 1), by air photos provided for examination by the Oregon State Department of Forestry Regional Office in Tillamook. Funding for the field work was donated by the Oregon Department of Geology and Mineral Industries and by Northwest Explorations of Denver, Colorado.

PREVIOUS WORK

Previous work within the study area, and the Tillamook Highlands as a whole, is virtually non-existent. Except for about 6 square kilometers around Cedar Butte mapped in detail (Nelson and Shearer, 1969), all study of the Highlands has been of a regional nature (Snively and

Wagner, 1963, 1964; Snavely et al, 1970; Warren et al, 1945). Only one other study is known to be in progress at this time in the Tillamook Highlands, an examination of the polarity and orientation of the remnant magnetization of the extrusive rocks (James McGill, 1979, Stanford University, personal communication).

SAMPLING

No systematic sampling program was followed. Samples were taken whenever the outcrop showed a feature, texture, etc., which deserved notice. Most of the samples used to define the rock units were taken early in the field season (i.e., the eastern half of the study area, see page 8, Field Work) with occasional samples taken later (in the western half) to check for variations. Samples were numbered consecutively as taken and given a prefix of KAC, the author's initials. All sample locations are marked on the Geologic Map, Plate 1.

CHAPTER II

LITHOLOGIC UNITS

INTRODUCTION AND NOMENCLATURE

It should be noted that, due to lack of previous work in the Tillamook Highlands, this study entails delineation and definition of lithologic units and is not merely the carrying of contacts from known units into unmapped regions. It is not the place for this author to suggest that the units or the names placed upon them for this study are anything but informal. Unit names, derived from prominent topographic features near definitive outcrops, are used for convenience only.

The study area is composed of five distinctive, mappable lithologic units of Eocene age (see Figures 2 and 3) excluding landslide debris and river alluvium (landslide material is mapped on the Geologic Map, Plate 1; river alluvium is not). The stratigraphically lowest and the oldest unit exposed is an exclusively marine sedimentary unit of siltstone and minor sandstone. It will be referred to as the Wilson River siltstone, the best exposures of this unit occurring in roadcuts in the canyon wall of the Wilson River near Jordan Creek.

Overlying the Wilson River siltstone is a submarine volcanoclastic sequence with minor intercalated shales and sandstones. The thickest continuous exposure of this unit is found on the slopes of Wolf Point, a prominent hill in section 14, and is therefore named the Wolf Point breccia.

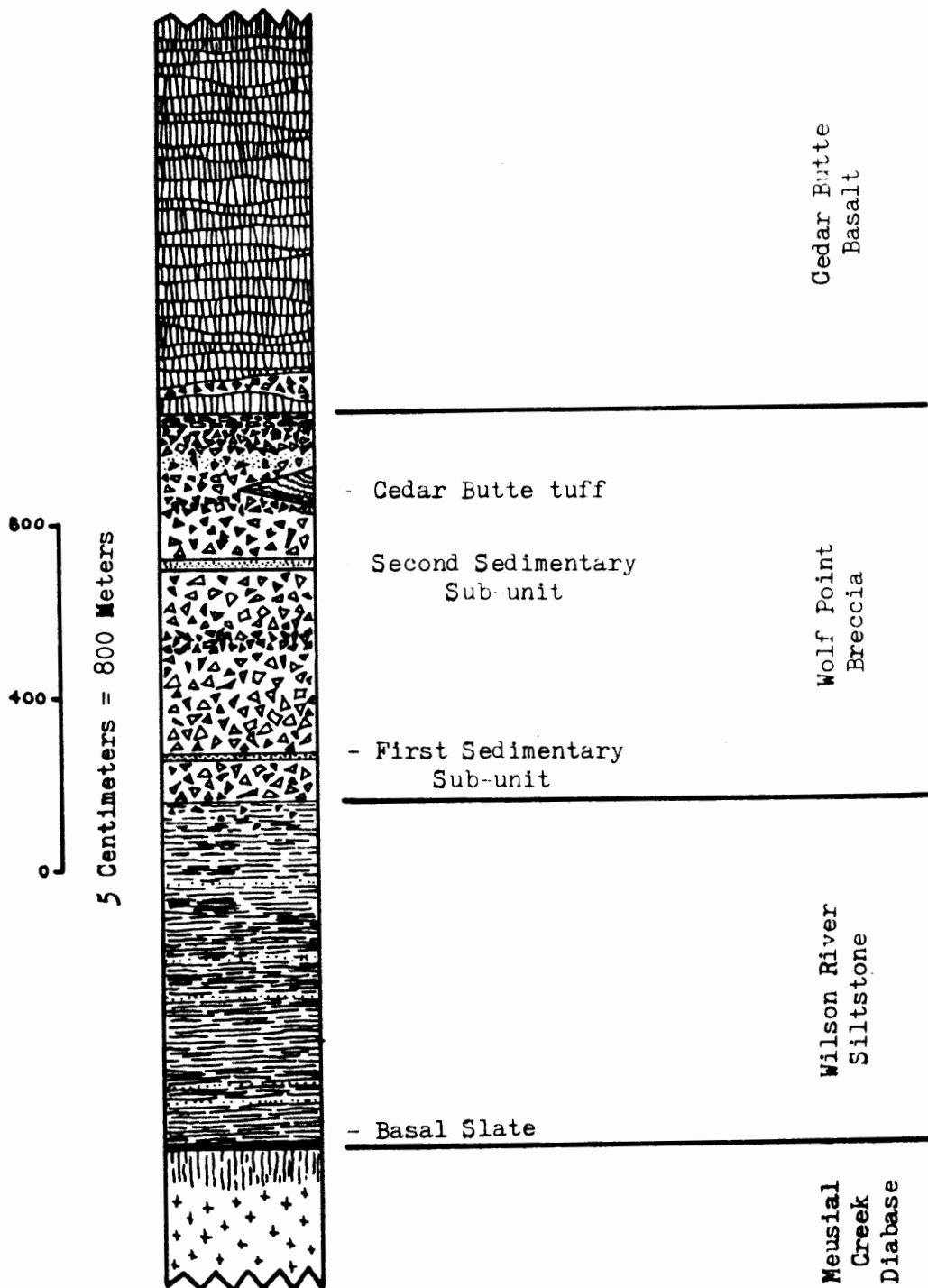


Figure 2. Diagrammatic stratigraphic column of the south-central margin of the Tillamook Highlands.

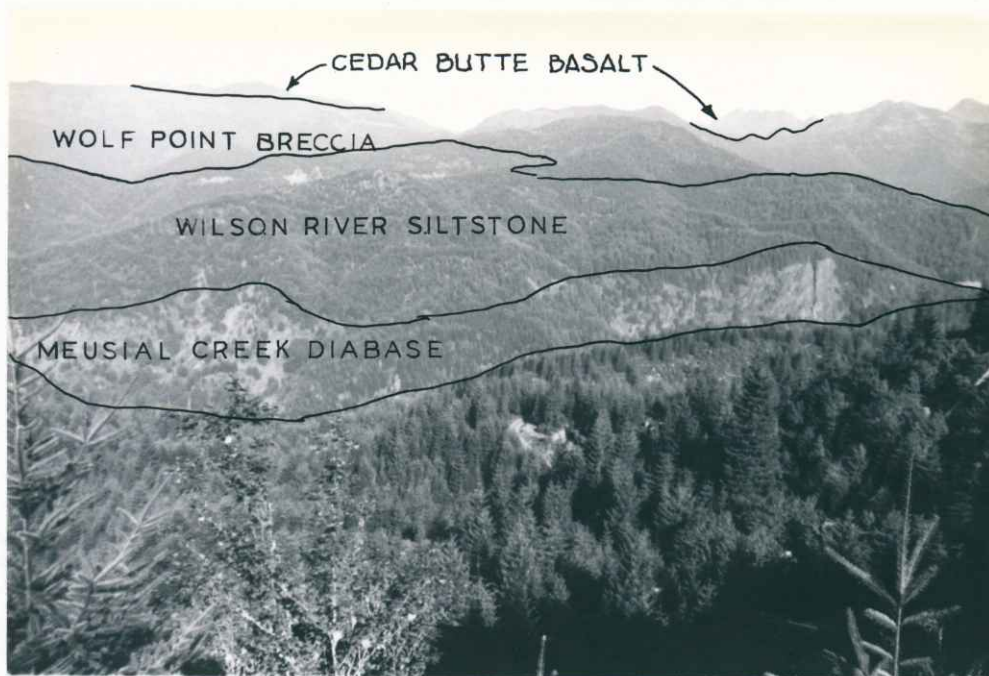


Figure 3. Looking northwest from Peak 1715 in section 26, with all units except the Cedar Butte tuff visible.

A lens-like sub-unit within the Wolf Point breccia has been given a separate name and mapped independently owing to its areal extent and distinctive lithology. It is a bedded crystal-rich tuff which crops out on the southern slopes of Cedar Butte in section 10 and will be referred to as the Cedar Butte tuff.

The stratigraphically highest unit in the study area is a sequence of subaerial basalt flows which will be known as the Cedar Butte basalt. These extrusive rocks were first seen and described by the author on the northern slopes of Cedar Butte.

A large diabasic sill intruding the Wilson River siltstones is called the Meusial Creek diabase. It is named for the excellent exposures found in the walls of Meusial Creek canyon.

The aforementioned nomenclature is used without further explan-

ation throughout the remainder of this study.

WILSON RIVER SILTSTONE

Definition

The Wilson River siltstone is the oldest unit exposed in the study area. It consists of at least 800 meters of rhythmically bedded, poorly indurated, sparsely fossiliferous brown siltstone with rare interbeds of lithic sandstone. The upper contact is not sharp but composed of intercalated siltstone and volcanoclastic material of the Wolf Point breccia. The lower contact, where it is exposed in the study area, is thermally metamorphosed to dark grey slate. A regional dip to the northwest of all units limits outcrops of the siltstone to the southeast half of the mapped area.

Description

The Wilson River siltstone is conformably overlain by and intertongues with the volcanoclastic material of the Wolf Point breccia. Due to the indistinct nature of the contact, the upper limit of the siltstone is arbitrarily placed at the point at which the percentages of siltstone and breccia are approximately equal. Early eruptions of the breccia seem to have been sporadic, with pauses in the eruption which allowed the deposition of layers of siltstone, producing the intertonguing found near the contact.

The presence of rounded blocks of breccia embedded in the siltstone near the upper contact indicates that the silts were in a totally unlithified state at the time of the eruption of the breccia. Density contrasts between the heavier breccia and the wet sediments allowed in-

vasion of blobs of the volcanics into the silts. Some of these blocks are over 2 meters in diameter.

The lower contact, at least in the study area, is with the intrusive Meusial Creek diabase. Over 800 meters of siltstone is exposed above the diabase. Within 20 meters of the intrusion the siltstone is thermally metamorphosed to a hard, grey slate which splits easily into flat slabs 1 to 2 centimeters thick. Secondary mineralization, probably induced by the emplacement of the intrusion, fills most fractures with a mixture of calcite and zeolites. The largest of these deposits measures 1 centimeter in thickness and extends for 25 centimeters.

The siltstone is rhythmically bedded throughout the unit (see Figure 4) except near the upper contact. Here loading-caused and invasion-induced soft sediment deformation has given the siltstone a chaotic or massive appearance. The major portion of the unit consists of rhythmically bedded siltstone, which is brown when fresh and weathers to a tan or light brown color and which breaks easily into pieces 0.5 to 1 centimeter thick along bedding planes. Fine laminations about 1 millimeter thick are visible parallel to the bedding planes but the rock is not fissile along these planes. These laminations are also visible in the slate near the lower contact.

The poorly indurated nature of the siltstone allows it to weather very easily and produce the thickest soil cover found in the study area. The competency of the unit is also very low and exposed sections slump and slide readily. These two features combine to make the siltstone the most poorly exposed unit in the study area. Outcrops are restricted to fresh roadcuts and landslide scarps. Even in fresh roadcuts the outer 10 to 25 centimeters begins to degrade immediately under the in-



Figure 4. Typical outcrop of the Wilson River siltstone, located in the NE $\frac{1}{4}$, sec. 26.

fluence of rain water and this layer must be removed to see the true orientation of the bedding.

Thin sandstone beds are sporadically intercalated with the siltstone. They are graded, fining upward, and commonly contain two or more sequences one on top of the other. The layers average 5 to 10 centimeters thick with the maximum thickness observed being 15 centimeters. The sandstones are more common in the upper portions of the unit. Load casts of sandstone into the underlying siltstone are common.

The thinness, scarcity and graded nature of the sandstones suggests that they are the depositional products of turbidity flows. Although a dearth of current indicators exists, those found point to the source of the currents as being due south of the study area. Inasmuch as the study area is located on the southern edge of the Highlands, the

currents must have come from an area unconnected with and pre-dating the Highlands. The Siletz volcanics are a probable source.

Petrography

The siltstone divulges no secrets to the petrographer that are not discernible to the field worker. It is composed of silt and clay sized particles with no identifiable grains visible even under the highest magnifications available (400x). The 1 millimeter scale laminations (see page 15) seen in handsample are readily visible through the microscope and appear to be due to small changes in the size of the grains making up the layers. Although not visible microscopically, tests with dilute hydrochloric acid indicate that the siltstone is partially cemented with calcite. Disaggregation of the siltstone produced no sand-sized fraction, indicating a very low energy environment of deposition.

While disaggregating a sample of siltstone during a search for microfossils, a number of thin flakes averaging 1 millimeter in length were found. They are composed of calcite, mica, zeolites, and possibly quartz. Whether these fragments are erratics rafted in from an outside source or are secondary mineralization produced epigenetically is not known. Their small size, composition, flatness and abundance suggests the latter.

The sandstones are immature litharenites (Folk, 1974) composed of 85 percent lithic fragments, 11 percent plagioclase feldspar fragments and 4 percent pyroxene crystal fragments (see Figure 5). Component grains are angular, showing virtually no rounding at all. Maximum grain size is 0.5 millimeter.

Lithic fragments are generally composed of randomly oriented

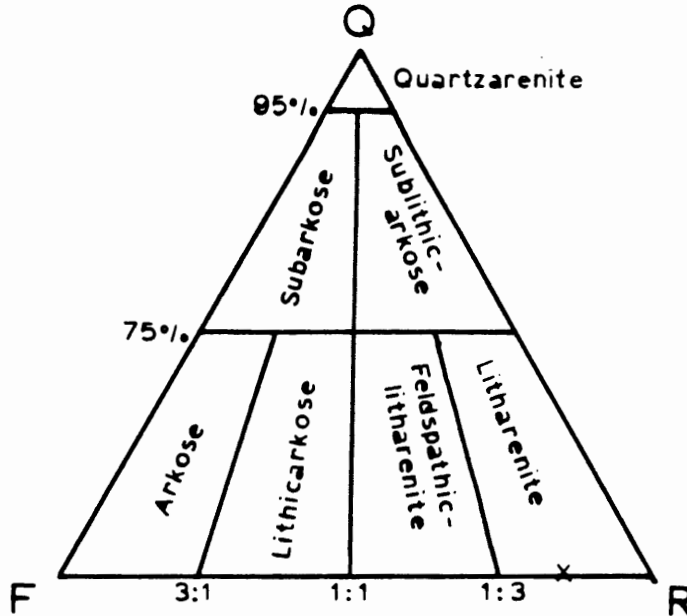


Figure 5. Quartz - rock fragment - feldspar diagram for the sandstone layers of the Wilson River siltstone.

microlites of labradorite set in a matrix of black or yellow opaque glass. These fragments are probably the products of rapid quenching and shattering of basaltic lava as it comes in contact with cold sea water. Some sedimentary lithic fragments of grey siltstone were also seen but make up a small percentage of the total lithic fragments.

The plagioclase and pyroxene grains are probably remnant phenocrysts of the basaltic lavas mentioned above. They are anhedral due to mechanical shattering and are rarely over 0.5 millimeter across. Both plagioclase and pyroxene are common phenocrysts in the lavas of the Coast Range of Oregon and Washington (see following section on the Cedar Butte basalt and Nelson and Shearer, 1969; Snively and Baldwin, 1948; Snively et al, 1968). The sandstones are silica cemented and are considerably harder than the surrounding siltstone.

WOLF POINT BRECCIA

Definition

The Wolf Point breccia marks the beginning of the volcanic period for the study area. It consists of over 900 meters of submarine volcanoclastic deposits with minor sedimentary interbeds. Its major constituents are flow breccias, pillow lavas, and hyaloclastites. It is underlain by the Wilson River siltstone and conformably underlies the Cedar Butte basalt (see Figure 6). It outcrops in a band which covers the center of the study area from the southwest corner to the northeast corner.

Description

The Wolf Point breccia is conformably overlain by the Cedar Butte basalt. The contact does not represent a change in lithologic composition, but a change in the conditions of deposition. The breccias are the result of basaltic lavas extruding into sea water; the basalts originate in these same lavas flowing out onto dry land. The upper limit of the breccia unit is defined by the first occurrence of subaerial basalt flows. The boundary between the subaerial and submarine material is not sharp, but spaced vertically over about one hundred meters of interbedded breccia and basalt. This indicates that the level of the sea was not constant or that the land was slowly subsiding at the time of deposition.

The lower contact of the Wolf Point breccia has been described in the section on the Wilson River siltstone.

The Wolf Point breccia is composed of four distinctive rock types;

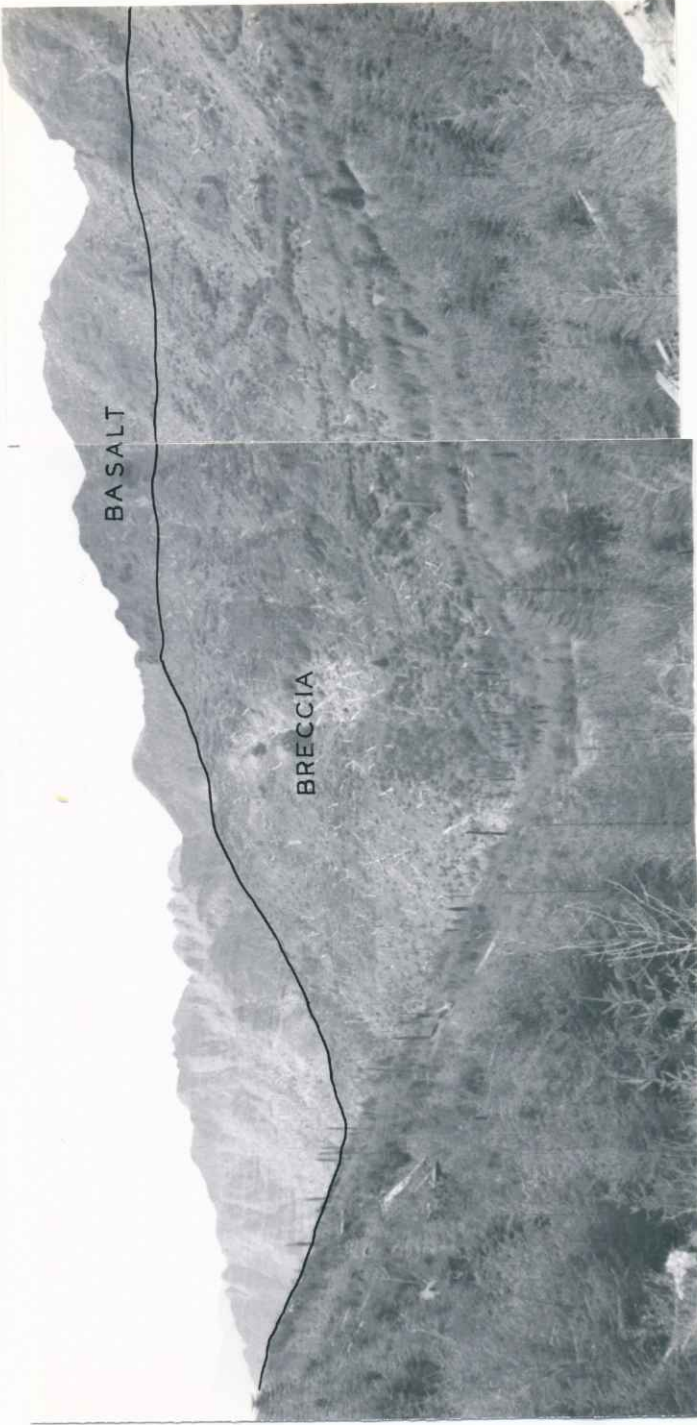


Figure 6. Panoramic view of the Cedar Butte basalt - Wolf Point breccia contact. The Sawtooth Ridge is in the left background, Cedar Butte is on the right. The South Fork of the Kilchis River flows through the center of the photograph.

flow breccia, pillow basalt, hyaloclastite and sedimentary sandstones and shales. By far the most common rock type, making up 85 percent of the units, the flow breccia is composed of angular to subangular basaltic clasts ranging in size from 0.5 to 10 centimeters, encased in a matrix of sand-sized glass fragments (see Figure 7). Zeolites are the usual cementing agent. The breccia is dark grey to black and weathers to a light grey or tan. The zeolite cement and glassy matrix weathers easily, releasing the harder basaltic clasts which gather to form a coarse, well-drained soil very similar to granite wash. This soil is easily recognized by its lack of tree cover and sparse undergrowth and is a great aid in mapping.

In outcrop the breccia appears massive, with no apparent structure at all. It occasionally weathers by spalling off sheets or layers up to 25 centimeters thick which produces nearly flat, pavement-like cliffs up to 50 meters high and which are visible from great distances (see Figure 8).

Near the upper contact of the Wolf Point breccia the cementation of the clasts is firmer in some flows and differential weathering allows the individual flows to be easily seen. These flows vary from 10 to 30 meters in thickness. Near the Kilchis Lookout (section 17) a thin (5 centimeters) red soil zone was observed between two of the flows. The shape of the zone indicates that the top of the flow is very irregular, almost chaotic.

Occasionally pods or lens-like outcrops of solid basalt are seen completely surrounded by the fragmental breccia. These basalt pods, up to 5 meters long and 3 meters high, commonly exhibit rudimentary columnar jointing similar to that seen in filled lava tubes. These pods



Figure 7. Close-up of the flow breccia of the Wolf Point breccia. The hand lens in the center is 6 centimeters long.

are interpreted as the product of self-insulation. As the quenched and shattered clasts of basalt pile up around the vent, the erupting lavas are progressively insulated from the cold sea water. This allows some lava to remain in a liquid state and force itself through the surrounding unconsolidated pile of debris to form a solid core or "mega-pillow."

Pillow basalts are the next most common rock type, making up about 10 percent of the unit. They are found intercalated with the breccia throughout the upper third of the unit. Pillow deposits are generally less than 10 meters thick with individual pillows up to 1 meter in diameter (see Figure 9).

The pillows are black, glassy and highly fractured and weather into angular blocks. Radial joint patterns are developed in some of the



Figure 8. Cliff of pavement-like breccia formed by spalling of weathered layers. The cliff is about 30 meters high.

larger pillows. A small amount of inter-pillow matrix composed of glassy fragments up to 10 centimeters across is always present. This matrix is grey in color, weathering to yellow or tan.

The least common of the volcanic rock types is a hyaloclastite composed of fragmental debris and glass enclosing scattered basaltic pillows (see Figure 10). These deposits are small, always less than 10 meters in thickness and not traceable laterally. The pillows are small in comparison to those of the pillow basalt section, being not greater than 0.5 meter across. The glassy, fragmental matrix weathers easily, taking on a reddish hue. The hyaloclastites are found only in the extreme upper portion of the Wolf Point breccia just below the contact with the overlying Cedar Butte basalt.

At least two sedimentary sub-units are included within the Wolf



Figure 9. Pillow basalts of the Wolf Point breccia in the NW $\frac{1}{4}$, sec. 2. Hammer is 30 centimeters long.

Point breccia. One is found just above the lower contact, the other about 350 meters below the upper contact.

The first sub-unit is located about 100 meters stratigraphically above the contact with the Wilson River siltstone and is represented by 10 meters of sandstone with very minor shales. It consists of numerous graded beds rarely more than 35 centimeters thick composed of fine to medium sized black sand, fining upward to a thick layer of brown shale. The sandstone from these beds is very hard and has been quarried to a minor extent for road metal.

About 350 meters below the upper contact of the Wolf Point breccia is the second and more extensive of the two known sedimentary sub-units. It consists of a series of interbedded shales and sandstones 25 meters in total thickness. The thickness and layered nature of these rocks

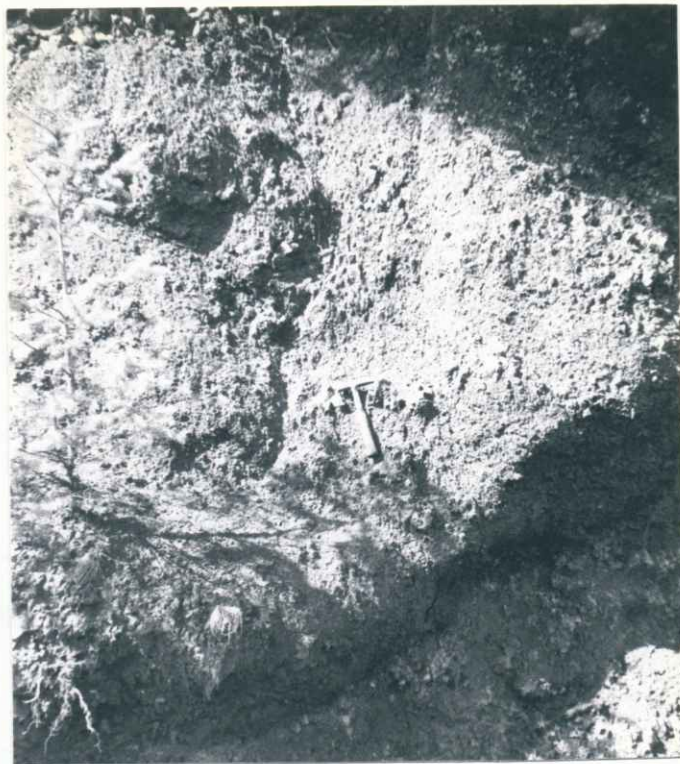


Figure 10. Hyaloclastite deposit in the Wolf Point breccia in the SE $\frac{1}{4}$, sec. 30. Hammer is 30 centimeters long.

makes them easily recognizable from a distance and readily differentiated from the surrounding volcanoclastic rocks (see Figure 11). Because of these features the sedimentary beds of the second sub-unit have been mapped to a limited extent throughout the study area (see Plate 1).

This sub-unit is composed of 75 percent sandstone and 25 percent shale. The sandstone is light grey to tan in color, weathering to grey, and is made up of coarse, angular grains in beds 0.25 to 1 meter in thickness. The beds do not appear to be graded. Current indicators on the bottom of the sandstone beds point to a direction of transport from the south to the north.

The shale is white to light tan, fossiliferous and tuffaceous with numerous fragments of flattened pumice visible on fresh surfaces. It is extremely fissile, parting into brittle sheets on the order of 1

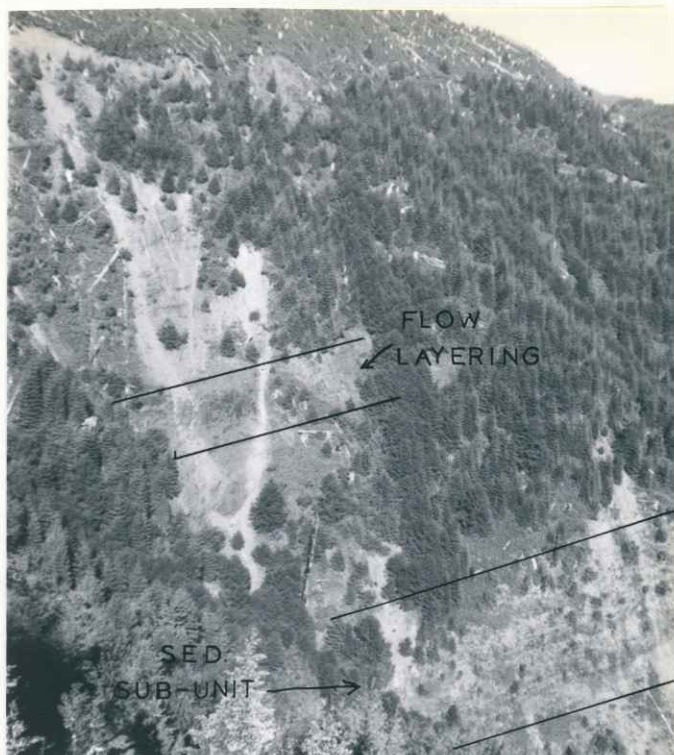


Figure 11. The upper one-third of the Wolf Point breccia in the N $\frac{1}{2}$, sec. 15, showing the second sedimentary sub-unit and flow layering of the breccia.

millimeter thick. The fissility is most noticeable in weathered sections. Shale beds range in thickness from a few centimeters to over 3 meters.

Evidence for a possible third sedimentary sub-unit is found in sections 27 and 34. Blocks of sandstone float are found about 50 meters above the contact with the Wilson River siltstone, but no in situ outcrop can be found. In handsample, this sandstone greatly resembles that found in the second sedimentary sub-unit described above, but the large stratigraphic distance between the two localities (about 400 meters) precludes a common stratigraphic source for both. It is tan in color, coarse-grained and with angular clasts. The largest blocks of this material found are about 30 centimeters on a side and show bedding

2 to 4 centimeters thick.

Petrography

The breccia is an agglomeration of glassy basaltic clasts cemented loosely together by zeolites and minor calcite. The clasts, ranging in size from 0.5 to 10 centimeters, make up about 85 percent of the rock. The remaining 15 percent is sand-sized rock and glass fragments and zeolites.

The clasts are of a porphyritic aphanitic hypocrystalline hypidiomorphic granular pyroxene basalt. Phenocrysts, which compose less than 2 percent of the rock, are glomeroporphyritic and consist of plagioclase feldspar and clinopyroxene. The plagioclase is labradorite in composition (An_{58} to An_{68}) with subhedral habit 0.75 to 1 millimeter long. The clinopyroxene is clear augite, subhedral to euhedral and 0.1 to 0.3 millimeter across. The matrix is a felted mass of plagioclase microlites, magnetite and glass. The microlites are of andesine and labradorite composition (An_{35} to An_{55}) and are subhedral to euhedral. The magnetite is anhedral, rounded grains less than 0.1 millimeter across. Most of the glass, originally brown to black in color due to high concentrations of magnetite dust, has now altered to yellow clays, probably of the smectite group.

The composition of the basaltic clasts as determined by point counting is recorded in Table I and also in Table III. The clasts of the Wolf Point breccia and the flows of the Cedar Butte basalt seem to share the same mineralogical composition and probably come from the same magma source. The only significant differences occur in the interstitial minerals (see Table III), the lower percentages found in the

TABLE I

COMPOSITION OF WOLF POINT BRECCIA CLAST
(SAMPLE KAC-39)

Plagioclase - phenocryst	6.7%
- microlite	39.7
- (total)	(46.4)
Augite - phenocryst	1.8
- microlite	26.9
- (total)	(28.7)
Magnetite	6.7
Clay and glass	14.8
<u>Zeolite</u>	<u>5.3</u>
Total	101.9%

breccia due probably to quenching and entrapment of the mineral as glass matrix. Chemical analysis of a clast can be found in Table VII. The mineralogical composition of the pillow lavas and the hyaloclastites is identical to the breccia.

The sandstones of the sedimentary sub-units fall into two definite categories; feldspathic litharenites and arkoses (see Figure 12). The sandstone of the first or lower sedimentary sub-unit (see page 24) is a feldspathic litharenite. It is composed of 50 percent rock fragments, 4 percent plagioclase grains and 5 percent accessory minerals. The rock fragments are angular to subangular volcanic rock debris with minor amounts of sandstone and shale fragments. The volcanic fragments consist of a felted to trachytic mass of plagioclase microlites set in a matrix of opaque material. The plagioclase grains are subrounded and

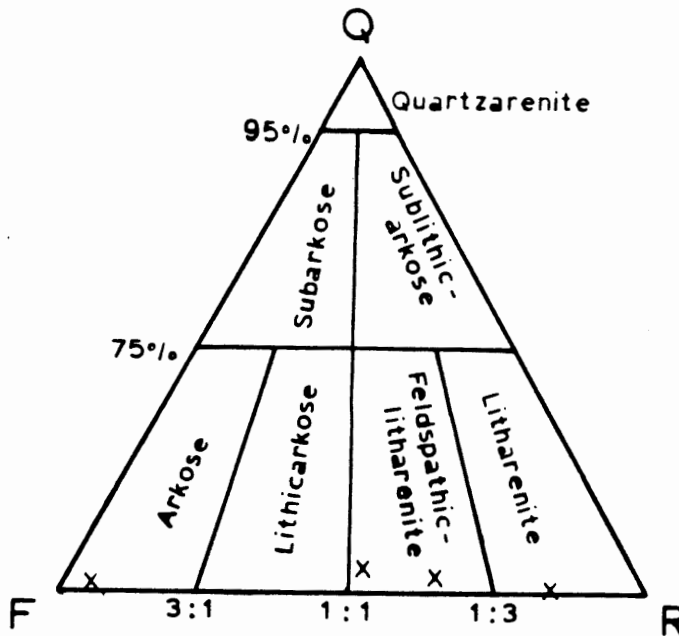


Figure 12. Quartz - rock fragment - feldspar diagram for all sandstones of the study area.

are of andesine and labradorite composition. The accessory minerals are angular to subrounded grains of augite, biotite, calcite, quartz, pyrite and magnetite.

Cement is calcite and may be derived in part from the numerous calcitic foraminifera tests found in the rock. The component grains of this rock are well sorted and immature with an average grain size of 0.1 millimeter.

During disaggregation of a sample (KAC-28) of this sandstone in preparation for a search for microfossils, erratic rock fragments were noted. These fragments are plate-like, not more than 4 millimeters in thickness and 1 centimeter across. The largest of the six specimens showed visible books of euhedral biotite, anhedral quartz and an opaque white mineral. Etching of the specimen with hydrofluoric acid and then treating it with a saturated solution of potassium cobaltinitrate showed

that the white, opaque mineral is rich in potassium ion. The mineral is presumed to be potassium feldspar. Mineralogically the erratics therefore have a granitic composition. There are no granitic rocks anywhere near the study area, indicating that the erratics were rafted in from a distant source.

The sandstone of the second or upper sedimentary sub-unit (see page 24) is also a feldspathic litharenite (see Figure 12). It consists of 60 percent lithic fragments, 20 percent plagioclase grains, 15 percent potassium feldspar and 5 percent accessory minerals. The lithic fragments are mostly volcanic in origin with only very minor shale and fine sandstone fragments. The volcanic fragments are angular, feld to trachytic masses of plagioclase microlites in a brown or black opaque matrix. Both the plagioclase and potassium feldspar grains are sub-angular to subrounded and for the most part are rectangular in outline. The accessory minerals consist of angular to subrounded grains of augite, pyrite, magnetite and hypersthene.

The component grains of this rock are not well sorted with grain size ranging from 0.5 to 2 millimeters. Lithic fragments are generally the largest and the accessory minerals show the greatest diversity in size. Cementing of the sandstone is by silica.

The sandstone which was not found in outcrop (see page 26) is an arkose (see Figure 12). It is composed of 10 percent lithic fragments, 40 percent plagioclase grains, 45 percent potassium feldspar and 5 percent accessory minerals. Again, the lithic fragments are volcanic and subrounded with an occasional well rounded grain. The feldspars are subrounded to rounded. The accessory minerals are subrounded to rounded grains of hematite, pyrite, magnetite, hypersthene and quartz.

The component grains are unsorted and more mature than the other sands found in the Wolf Point breccia. Grain size ranges from 0.5 to 5 millimeters with rare grains to 10 millimeters. The volcanic lithic fragments are the largest, the 10 millimeter grains being basaltic and well rounded. Rounding is pronounced, with all grains being at least subrounded.

CEDAR BUTTE TUFF

Definition

The Cedar Butte tuff is actually an event within the depositional history of the Wolf Point breccia. Owing to its obvious lithologic differences with the breccia and its areal extent and thickness, it is mapped and described separately. This unit is a lens-like deposit of green to grey crystal vitric tuff bounded above and below by the breccia. Its maximum thickness is 100 meters, thinning to zero at the lateral extremities. It is well bedded with a maximum bed thickness of 30 centimeters near the center of the unit and a minimum of 1 centimeter at the edge. It is found only on the south side of Cedar Butte, mostly in section 10.

Description

The Cedar Butte tuff marks a single event during the formation of the Wolf Point breccia and the upper and lower contacts are therefore with the breccia. Reworking of the tuff by water and piling of material near the eruptive center has produced a range of dips generally greater than the surrounding breccia (see Plate 1). This gives the contacts an angular discrepancy but they are nonetheless chronologically conformable.

The tuff is grey in color and weathers to green in the thicker sections. Thinner edges of the unit contain a greater percentage of iron-rich clay minerals and have a reddish color. A red soil zone commonly covers the unit. Bedding thicknesses range from 1 centimeter near the edges to a maximum of 30 centimeters near the central portions. The material of the deposit is unconsolidated and crumbles easily on exposure to the elements. It is granular, consisting originally of lapilli up to 1 centimeter across. Grain size grades laterally, fining to sand-sized particles at the unit extremities. Volcanic bombs up to 10 centimeters are found in the thickest beds.

Euhedral clinopyroxene crystals are abundant throughout the unit. Near the center they are as large as 3 centimeters long, grading to 1 to 2 millimeters in the distal portions. Fragments of these crystals collect as shiny black sands where there is surface run-off (e.g., trails and roads). These sands serve as a distinct indicator and aid in mapping through covered or deeply weathered terrain.

A lava flow which appears to be the flow-equivalent of the tuff is found abundantly as float near the center of the unit but was not seen in outcrop. It consists of a dense, black basalt containing up to 40 percent phenocrysts of pyroxene. It is assumed by the author that this material represents a portion of the parent magma which invaded the tuff deposits around the vent without disintegrating into lapilli-sized fragments.

The thickening of the beds, larger lapilli size, larger crystal size and the presence of bombs near the center of the unit suggests that the eruptive vent is located in the NW $\frac{1}{4}$, SE $\frac{1}{4}$ or the SW $\frac{1}{4}$, NE $\frac{1}{4}$ of section 10. The material is obviously water worked but no evidence

could be found to indicate if the tuff was erupted through water from a submarine source or into water from a subaerial location.

Petrography

The Cedar Butte tuff is a pyroxene-rich crystal-vitric tuff. It is composed primarily of yellow-orange sideromelane, altered in part to smectite. Accelerated weathering on outcrop faces has allowed the formation of nontronite, which gives the characteristic green color to weathered sections. The nontronite occurs commonly in the form of spherulites. Unidentified ferruginous clays in the thinner, finer-grained distal portions give the unit extremities their reddish tint. The sideromelane glass still retains the outline of flattened shards and angular chunks up to 1 centimeter across in unaltered portions of the rock.

Approximately 25 percent of the tuff is phenocrysts of clinopyroxene. These phenocrysts are euhedral except where mechanically broken, probably by stresses at the time of eruption. Both augite and pigeonite are represented, with augite being by far the more common. Microscopic examination of a bomb from the tuff shows that about 10 percent of these crystals were eroded and embayed at the time of eruption. These characteristics are much more common in the pigeonite crystals. Some crystals are seen to contain inclusions of opaque material. The embayment of crystals and the opaque inclusions are not seen in the free crystals of the unconsolidated tuff, only on those of the bombs. The imperfect crystals are physically weaker and more subject to shattering during the eruptive process. The size of the phenocrysts ranges from 0.5 to 3 centimeters.

The flow-equivalent of the tuff is a porphyritic aphanitic hypocrystalline hypidiomorphic granular andesine basalt. Phenocrysts, which compose up to 40 percent of the rock, are euhedral to subhedral augite with minor pigeonite. They average 0.5 to 2 centimeters across and are commonly fractured with kelyphitic rims of microcrystalline amphibole lining the fracture walls and occasionally the crystal outlines. In some crystals the alteration has proceeded to the extent of forming pseudomorphs of microcrystalline amphibole after pyroxene.

Very rare phenocrysts of plagioclase are present. They reach a maximum size of 3 millimeters and are heavily embayed and rounded. Compositions are in the labradorite range with An percentages near 55.

The matrix is composed of a felted mass of plagioclase, pyroxene, magnetite, and palagonite. The plagioclase is in the form of microlites of andesine composition with occasional laths of oligoclase and labradorite (An_{28} to An_{53} , average of An_{43}). Average lath length is 0.2 millimeters. Normal zoning is found in most laths. Pyroxene in the matrix is interstitial, rounded and anhedral. Size of the grains varies from 0.1 to 0.5 millimeters. The grains proved to be too small to obtain the 2V angle of the optic axes, which is the major criteria used to differentiate augite from pigeonite. The magnetite occurs in various habits, the most common being a rectangular shape 0.1 to 0.5 millimeter across. It also occurs as anhedral grains and as parallel needles which thread their way through the matrix for up to 2 millimeters. Palagonite occurs as very small interstitial grains concentrated in isolated areas of the rock.

The mineral composition of the flow-equivalent as determined by point count is represented in Table II. Major oxide composition as

TABLE II
MINERAL COMPOSITION OF THE FLOW-EQUIVALENT
OF THE CEDAR BUTTE TUFF

	KAC-4	KAC-19
Pyroxene - phenocryst . . .	31.5% . . .	38.5%
- microlite . . .	17.1 . . .	16.8
- (total)	(48.6) . . .	(55.3)
Pyroxene alteration	5.0 . . .	9.1
Plagioclase - phenocryst . . .	2.2 . . .	0.0
- microlite . . .	29.1 . . .	20.4
- (total)	(31.3) . . .	(20.4)
Magnetite	9.3 . . .	12.6
<u>Palagonite</u>	<u>5.8</u> . . .	<u>2.8</u>
Total	100.0	100.0

determined by commercial analysis is found in Table VII.

CEDAR BUTTE BASALT

Definition

The Cedar Butte basalt is the stratigraphically highest unit in the study area. It consists of at least 900 meters of subaerial basalt flows 20 to 30 meters thick. The lower contact interfingers with the Wolf Point breccia. The upper contact, if there is one, is not seen in the study area. Outcrops of the basalt are restricted to the north-west half of the mapped area.

Description

The Cedar Butte basalt is the stratigraphically highest unit in

the study area. The upper limits of the basalt are not found within the confines of the mapped area. Therefore its true thickness is not known, but at least 900 meters is exposed. The lower contact is conformable and interfingers with the Wolf Point breccia. Intercalated basalt and submarine breccia are found in the first 100 meters above the contact, which is defined as the first occurrence of subaerial material. The lower contact represents the sea level interface at the time of the volcanism. Continuous eruptions below sea level produced the breccia which built up to sea level, producing the intercalated zone. Once high enough to be continuously above sea level the subaerial basalts were deposited. The thickness of the intercalated zone (about 100 meters) suggests that the eustatic level of the sea was changing or that the land was slowly subsiding.

Individual flows are 20 to 30 meters thick and consist mainly of a highly fractured entablature of irregularly shaped and sized columns (see Figure 13). Well-defined colonnades are occasionally present and are restricted to the lower quarter of the flows. Mechanical weathering by the freeze - thaw cycle is the predominant form of rock breakdown and this tends to produce impressive cliffs with basal talus slopes (see Figure 5).

The rock is black and dense with only occasional macroscopic crystals. Upon weathering it forms a thin rind of tan or orange colored clays. It is essentially non-vesicular, with gas-produced voids being found infrequently and then only in the basal portions of the flows.

K - Ar dating of the basalts (Robert Duncan, 1979, unpublished data) gives an age of 40 to 45 million years, or upper - middle to middle - upper Eocene. Paleomagnetic data (James McGill, 1979, personal



Figure 13. Contact between the Wolf Point breccia and the Cedar Butte basalt showing the differing outcrop textures. Located on the south side of Cedar Butte, N $\frac{1}{2}$, sec. 10.

communication) shows that the basalts have rotated about 45° clockwise since their extrusion.

Petrography

The rock of the Cedar Butte basalt is a porphyritic aphanitic hypocrySTALLINE hypidiomorphic granular pyroxene basalt. Phenocrysts of plagioclase and pyroxene make up about 5 percent to 10 percent of the rock and are set in a matrix of plagioclase, pyroxene, magnetite, glass and secondary minerals.

The phenocrysts of plagioclase are 0.5 to 1 millimeter across, subhedral, embayed and tend to be glomeroporphyritic. Opaque inclusions are common. Compositionally, they are low calcium labradorite, normally zoned with cores of An_{55} to An_{60} and rims of An_{45} to An_{50} . Occasionally

crystals of bytownite are found (An_{72}), but they make up less than 2 percent of the total phenocryst population.

The pyroxene phenocrysts are generally smaller, 0.3 to 0.5 millimeter across and are anhedral. They are rarely glomeroporphyritic. Measurements of 2V angles show that they are composed of slightly sub-calcic augite. While anhedral, they are not embayed and rarely contain inclusions. No direct alteration of the augite was observed.

One subhedral phenocryst was identified as olivine, the only occurrence of olivine noted in the Cedar Butte basalt or in the Wolf Point breccia.

The matrix is a trachytic assemblage of plagioclase and augite with minor magnetite, glass and secondary minerals. The plagioclase microlites are subhedral, 0.1 millimeter long and of andesine and labradorite composition (An_{45} to An_{55}). The trachytic texture is best developed in the plagioclase microlites in the immediate vicinity of phenocrysts and seems to be caused more by the movement of the phenocrysts rather than the flowing of the entire mass. The augite is interstitial, anhedral and 0.1 millimeter across. Magnetite is found in the form of interstitial anhedral grains, square euhedral crystals up to 0.2 millimeter across and as parallel needles with a maximum length of 0.5 millimeter. Glass in the form of sideromelane is rare, having for the most part devitrified to smectite. The smectite occurs as squarish patches, commonly with a rim of disseminated magnetite dust.

Table III contains the rock compositions as determined by point count of the Cedar Butte basalt. Also included in the table are the compositions of the clast from the Wolf Point breccia, the flow-equivalent of the Cedar Butte tuff, and the basaltic dikes of the study area

TABLE III

POINT COUNT DATA FOR ALL BASALTIC ROCKS IN THE STUDY AREA

MINERAL	SAMPLE NUMBER									
	KAC-13	KAC-14	KAC-16	KAC-17	KAC-40	KAC-39	KAC-04	KAC-19	KAC-12	KAC-03
Plagioclase - phenocrysts	1.6	7.4	3.9	5.9	8.1	6.7	2.2	-	13.1	8.3
- microlites	41.9	36.9	37.2	37.8	38.0	39.7	29.1	20.4	40.5	15.3
- (total)	(43.5)	(44.5)	(41.1)	(43.7)	(46.1)	(46.4)	(31.3)	(20.4)	(53.6)	(23.6)
Pyroxene - phenocrysts	2.3	0.5	1.1	0.5	2.0	1.8	31.5	38.5	0.8	-
- microlites	37.3	39.1	35.6	35.4	30.9	26.9	17.1	16.8	11.3	12.5
- (total)	(39.6)	(39.6)	(36.7)	(35.9)	(32.9)	(28.7)	(48.6)	(55.3)	(12.1)	(12.5)
Pyroxene alteration	-	-	-	-	-	-	5.0	9.1	-	-
Magnetite-ilmenite	10.6	9.2	8.6	8.1	18.6	6.7	9.3	12.6	7.1	-
Glass and devitrification products	6.3	6.9	9.4	8.4	2.4	14.8	5.8	2.8	27.2	58.9
Zeolites	-	-	-	-	-	5.3	-	-	-	0.3
Unidentifiable material	-	-	4.2	3.9	-	-	-	-	-	5.0
Total	100.0	100.2	100.0	100.0	100.0	100.1	100.0	100.2	100.0	100.3

Samples KAC-13, KAC-14, KAC-16, KAC-17, and KAC-40 are from the Cedar Butte basalt. Sample KAC-39 is a clast from the Wolf Point breccia. Samples KAC-04 and KAC-19 are from the flow-equivalent of the Cedar Butte tuff. Samples KAC-12 and KAC-03 are from basaltic dikes.

for comparison purposes.

MEUSIAL CREEK DIABASE

Definition

The Meusial Creek diabase is a sill-like intrusion which invaded the Wilson River siltstone. It possesses a glassy chilled margin with rudimentary columnar jointing. This grades into a massive central core of white to green diabase. In the study area at least 300 meters of this unit is exposed. The lower contact of the unit is not exposed. Outcrops of the intrusion are restricted to the southeast corner of the study area.

Description

The Meusial Creek diabase invades the Wilson River siltstone in a sill-like manner. The contact between the two is concordant in relation to the bedding of the siltstone but thickness of the siltstone varies from the major outcrop to the upfaulted outcrop in section 22 (see Plate 1 and Cross Section B - B', Plate 2). This discrepancy in thickness can only be explained by discordant tendencies of the intrusion at depth, either stepping up or stepping down between bedding planes. The actual contact is sharp and well-defined. Contact metamorphism has baked the siltstone near the contact into slate, the loss of the heat needed to do this quenching the edge of the intrusion and producing a glassy chilled margin.

Within 100 meters of the contact the chilled margin contains poorly formed columnar joints of chaotic orientation. These columns become less recognizable further from the contact until the intrusion

becomes massive at about 150 meters. Columns are 0.5 meter across with size increasing slightly with depth.

Mechanical weathering is the most prevalent form of rock breakdown, forming impressive cliffs up to 100 meters tall (see Figure 3). Soil cover is thin to non-existent, indicating that chemical weathering is very slow.

Hand sample appearance of the diabase varies greatly with distance from the upper contact. Near the contact quenching has produced a coarse-grained, glassy rock which is black, weathering to dark brown. Easily visible are laths of plagioclase up to 3 millimeters long and patches of soft, black clay up to 10 millimeters across.

Deeper in the unit the rock is less glassy, rare zeolites are found and the amount of clay is greatly reduced. The rock is more grey than black and weathers to form a tan crust. At the core of the intrusion the rock is almost white and made up largely of feldspar with irregular patches of mafic material. Dark, sharply defined patches up to 15 centimeters across are common in the core and are presumed to be autoliths. They resemble the rock types found in the upper reaches of the unit and must have broken free and settled into the lower portions of the intrusion. White streaks and pods up to 25 centimeters long consisting almost entirely of feldspar are also found in the core. They are probably the last portions of the intrusion to solidify and make up the "micropegmatite" fraction common in diabases (Williams et al, 1954).

Below the core the zones are found again in appropriate order. However, no columnar jointing can be found. The base of the intrusion is not found in the study area, but it is assumed that the layering seen

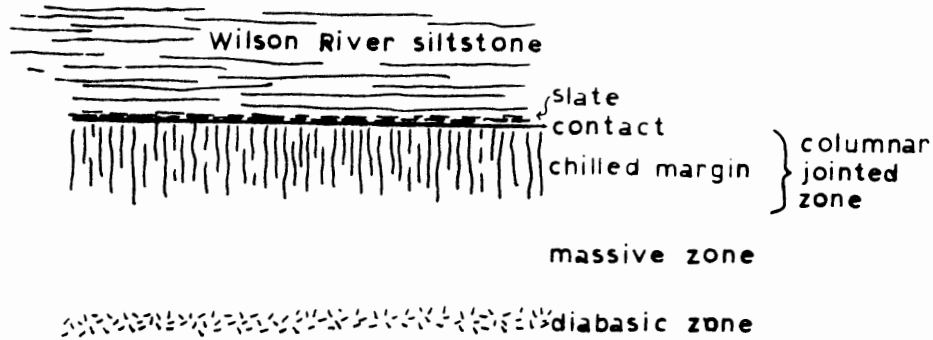


Figure 14. Hypothetical cross section through the upper half of the Meusial Creek diabase showing textural and compositional zones.

in the upper half is repeated in the lower half.

Petrography

Petrographic variations are as pronounced as those seen in hand sample. In the chilled zone the rock is a medium grained hypocrySTALLINE hypidiomorphic granular mixture of plagioclase and augite with minor magnetite and calcite set in an opaque clay matrix (see Table IV).

The plagioclase is in the form of subhedral laths 1 to 2 millimeters long of andesine composition (An_{33} to An_{45}). Rare crystals of labradorite (up to An_{54}) up to 3 millimeters long are found. These crystals are irregular with rounded, embayed margins. All plagioclase laths are normally zoned, with some of the larger crystals showing multiple zoning episodes.

The augite is anhedral to subhedral and is up to 1 millimeter across. The crystals are heavily fractured and most exhibit some degree of undulous extinction. They are sometimes found enclosing the ends of plagioclase laths in the beginning of subophitic texture.

The magnetite (based upon reflected light coloration, this

mineral is probably an intergrowth of magnetite and ilmenite, but will be called magnetite in this study) grains range from anhedral grains and euhedral crystals averaging 0.25 millimeter across to plates and long slender needles up to 1 millimeter long. Most of the euhedral crystals are found within the clay of the matrix.

Calcite is found as anhedral patches up to 0.5 millimeter across within the larger patches of clay. It is probably a deuteric mineral formed by the breakdown of the calcic plagioclase crystals.

The original glass matrix is completely devitrified to an unidentified opaque to translucent clay which is reddish brown in reflected light. The clay exhibits a "mud-crack" texture which indicates that it is of the hydrous, swelling family. Heating of the rocks during preparation of the thin sections caused dessication and shrinking of the clay and the resulting texture.

In the core of the intrusion felsic constituents increase and mafics decrease (see Table IV and Figure 15). Devitrification-produced clays are of course absent but have been replaced by a considerable amount of vapor-phase secondary minerals. Apatite is found as a very minor accessory mineral in the core.

The plagioclase in the core is smaller in size, 0.3 to 1 millimeter, and more sodic, An_{22} to An_{45} , than that of the chill margin (see Figure 15). It is commonly found in a state of "decay," characterized by highly embayed margins and a mottling of the crystal body with inclusions of clay and quartz. This process is usually advanced to the point of obscuring the albite twin lamellae.

Augite crystals are larger in the core than near the contact, averaging 2 to 3 millimeters. Subophitic and ophitic textures are well

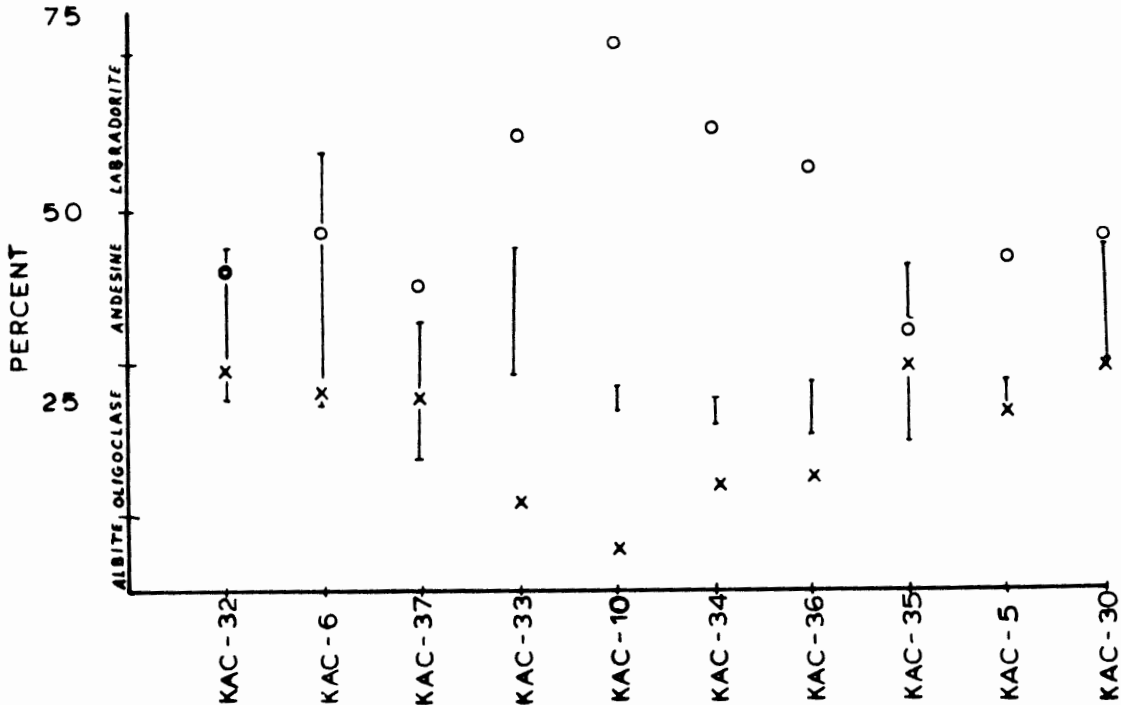


Figure 15. Mineral variation within the Meusial Creek diabase. For locations of sample points see Figure 16. o - % feldspar; l - An content; x - % pyroxene.

developed. The crystals are anhedral to subhedral.

Magnetite changes little in form and amount from the margin to the core, remaining variable in size and habit. In the core, however, it does have a tendency to cluster as small (0.1 millimeter) euhedral grains around the edges of the larger augite crystals.

Secondary mineralization is more advanced in the core than might be expected. In places up to 17 percent of the rock is composed of nontronite (see Table IV) with minor chlorite and an unidentifiable yellow microcrystalline substance, possibly vermiculite. This can be explained by the rapid quenching of the margin of the intrusive which produced an impermeable sheath around the core. This sheath trapped the volatile components of the magma as they exsolved during crystallization, pro-

ducing a very volatile rich environment and the evolution of minerals normally associated with deep weathering. Thus nontronite and chlorite (listed together as nontronite in Table IV) and the "decayed" aspect of the feldspars are the result of "internal weathering" caused by the trapping of the volatiles.

Apatite is a minor accessory mineral found only in the core. It is euhedral to subhedral and 0.3 to 0.5 millimeter long. Fluid-filled inclusions are present and fairly common although very small (0.01 millimeter). All inclusions contain clear, cubic microlites, opaque anhedral grains and some contain gas bubbles.

Within the core are found streaks of felsic rock containing very little mafic fraction. These presumably represent the very last portions of the magma to solidify. It is composed of the very sodic plagioclase oligoclase (An_{22}), with minor augite and apatite and substantial nontronite (see sample KAC-10, Table IV). Very rare, rounded grains of olivine were also found.

Definite trends in mineralogy occur from the margin to the core of the intrusion (see Figure 15). The amount of plagioclase increases and the amount of augite decreases toward the core. The An content of the plagioclase, while showing much greater variation near the margin, generally shows a decline toward the core.

The gradational nature of the unit, from the columnar joint chill margin to the massive subophitic zone to the ophitic core and the major and minor mineral constituents is typical of a diabase. The plagioclase is somewhat more sodic than is normal for the classic diabase, being andesine rather than labradorite, so the term andesine diabase is probably more appropriate.

TABLE IV

POINT COUNT DATA OF THE
MEUSIAL CREEK DIABASE

MINERAL	SAMPLE NUMBER									
	KAC-32	KAC-06	KAC-37	KAC-33	KAC-10	KAC-34	KAC-36	KAC-35	KAC-05	KAC-30
Plagioclase	42.1	47.3	40.0	59.0	71.7	60.1	55.6	33.8	43.3	47.1
Pyroxene	28.1	26.0	25.5	11.6	5.2	13.5	13.8	28.8	22.2	28.6
Olivine	-	-	-	-	0.2	-	-	-	-	-
Magnetite	7.4	7.3	6.0	5.9	4.2	7.3	5.6	2.5	8.8	6.3
Devitrified glass and unidentified clay	21.4	9.5	19.7	5.5	-	5.5	7.4	19.2	15.1	12.6
Nontronite	-	9.9	8.8	15.6	17.4	10.3	15.3	12.9	10.6	5.5
(total secondary)	(21.4)	(19.4)	(28.5)	(21.1)	(17.4)	(15.8)	(22.7)	(32.1)	(25.7)	(18.1)
Calcite	1.0	-	-	-	-	-	-	-	-	-
Apatite	-	-	-	2.4	1.3	3.3	2.2	-	-	-
Zeolites	-	-	-	-	-	-	-	2.7	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.9	100.0	100.1

Samples are in order down from the upper contact.

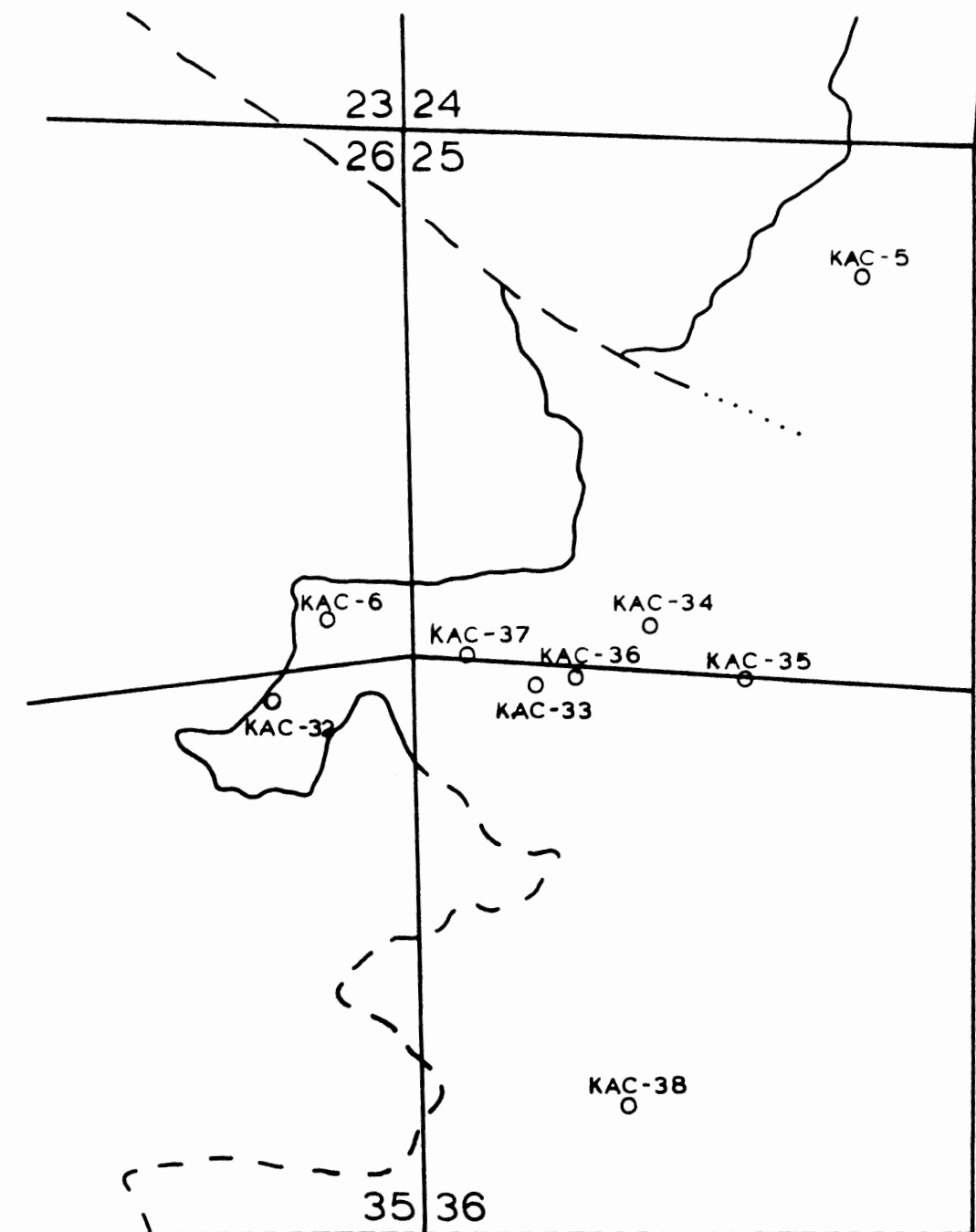


Figure 16. Southeast corner of the study area showing the contact between the Wilson River siltstone and the Meusial Creek diabase and sample locations in the diabase.

Locations of all samples taken in the Meusial Creek diabase are shown in Figure 16.

DIKES

Definition

The discordant intrusive rocks of the study area are all basaltic in composition. Thicknesses range from 20 centimeters to 3 meters with columnar jointing developed in the thicker dikes. Dikes are found throughout the study area but are more common in the northeast quarter. Those with thicknesses over 1 meter are plotted on the Geologic Map, Plate 1.

Description

The dikes in the study area range in thickness from 20 centimeters to over 3 meters. The surface traces of the thicker dikes are straight, showing that they are more or less vertical. Thin dikes have a tendency to wander in an angular, random manner as the intrusion first cuts across the grain of the host rock and then follows along it (see Figure 17).

Dikes over 1 meter in thickness possess a preferred orientation with surface traces trending approximately N30W (this is discussed further in Chapter IV, Structure). At least one dike, in the NE $\frac{1}{4}$, sec. 10, can be traced into the Cedar Butte basalt and then lost, and it is assumed that at least a portion of these dikes are feeders for the basalt flows. The largest dike in the study area can be traced for over 0.5 kilometer through the southern half of section 10 and has up to 8 meters of relief with the surrounding terrain.

At least two of the large dikes (one in the NE $\frac{1}{4}$, NE $\frac{1}{4}$, sec. 10,

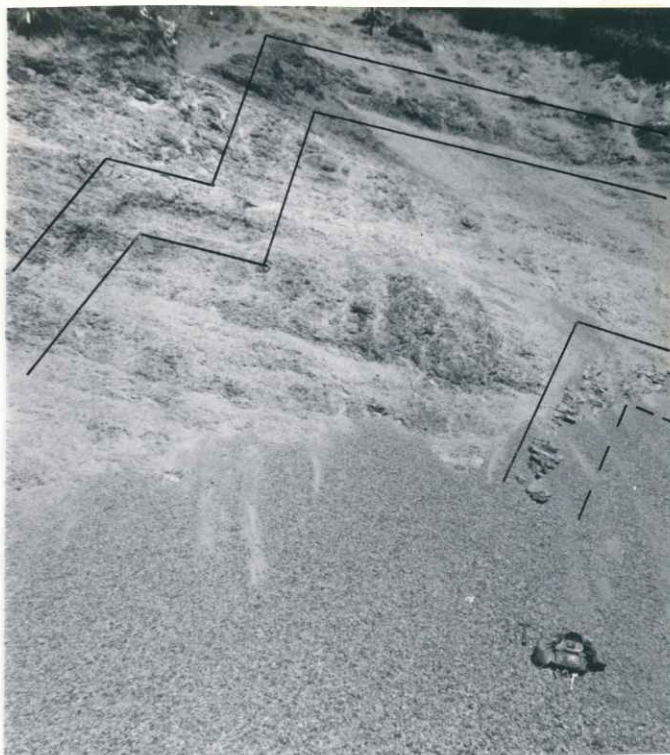


Figure 17. The angular wandering of thin dikes in the Wilson River siltstone. Located in the SE $\frac{1}{4}$, sec. 24.

the other in the SE $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 2) have altered the Wolf Point breccia, producing a zone of spheres at least 2 meters wide. This "ball bearing" zone is composed of loosely cemented brown spheres 1 to 2 centimeters in diameter. They can be easily plucked from the outcrop by hand. The spheres are composed of an amorphous brown matrix set with 1 millimeter patches of zeolites. The zeolites make up about 10 percent of the sphere. There is no apparent internal structure. These might be a form of spherulites produced by the thermal action of the dike on the breccia, but no truly satisfactory explanation has yet been found.

In hand sample the dikes are composed of dense, black basalt with limited numbers of feldspar phenocrysts. Weathering produces a thin, brown crust.

Petrography

The rock composing the dikes is a hypocrystalline hypidiomorphic granular porphyritic aphanitic basalt. It is composed of phenocrysts of plagioclase and rare augite set in a matrix of plagioclase and augite microlites and abundant black glass.

The plagioclase phenocrysts are subhedral, up to 1 millimeter across, and composed of normally zoned labradorite. Cores of the crystals average An_{67} and rims An_{54} . The augite phenocrysts are anhedral to subhedral and commonly fractured. One phenocryst, 0.5 millimeter long, was tentatively identified as olivine.

The groundmass is composed of microlites of andesine, An_{35} to An_{48} , and anhedral augite grains set in a matrix of black glass. This glass has in places devitrified to translucent orange smectite. Accessory magnetite is found as squarish grains up to 0.5 millimeter across. In some dikes the large amounts of black glass masks the true percentages of magnetite. Point count data of selected dikes is found in Table V.

TABLE V
MINERAL COMPOSITION BY POINT COUNT
OF SELECTED DIKES

	KAC-03	KAC-12
Plagioclase - phenocryst . . .	8.3 . . .	13.1
- microlite . . .	15.3 . . .	40.5
- (total) . . .	(23.6) . . .	(53.6)
Pyroxene - phenocryst . . .	0.0 . . .	0.8
- microlite . . .	12.5	11.3
- (total) . . .	(12.5) . . .	(12.1)
Glass and smectite	58.9 . . .	27.2
Unidentifiable clays	5.0 . . .	0.0
Zeolites	0.3 . . .	0.0
<u>Magnetite</u>	<u>* . . .</u>	<u>7.1</u>
Total	100.3	100.0

* in KAC-03 black glass masked the true percentage of magnetite.

CHAPTER III

GEOMORPHIC FEATURES

LANDSLIDES

Four major landslides are found within the study area. To simplify this discussion, the slides will be known as A, B, C and D as shown on the landslide location map, Figure 18. In all, these slides cover about 6 square kilometers of ground. The largest, C, located on the north side of Wolf Point, covers over 3 square kilometers (see Figure 19).

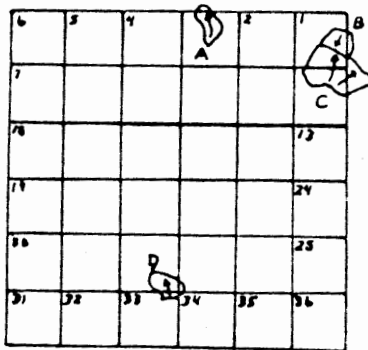


Figure 18. Location map of landslides.

Three of the four slides, B, C, and D, resulted from the failure of the Wilson River siltstone. The siltstone, due to its incompetent nature, is the least stable unit in the study area and it is not surprising to find evidence of its movement. Slides C and D occurred near the Wilson River siltstone - Wolf Point breccia contact and include considerable amounts of the breccia in the slide debris.



Figure 19. Looking east to slide "C", left of center, and Wolf Point, right of center.

The remaining slide, A, occurred wholly within the Wolf Point breccia. Its location is near the extrapolated position of the second and highest sedimentary interbed (see page 24) and these rocks may have been instrumental in the initiation of the slide. This slide seems to have been especially mobile, moving down a side canyon to the North Fork of the Kilchis River and turning through 60° to follow the valley. The river has cut through the toe of the slide exposing blocks of breccia up to 2 meters across and sections of tree trunks 3 meters long.

All of the slides except for B are found on slopes with northern aspect. At the latitude of the study area, these slopes receive little or no direct sunlight during the months of greatest rain and snowfall. Without the drying effects of the sun, the slopes would remain wet longer, allowing meteoric water to penetrate deeper and eventually

leading to slope failure. The one slide with southern aspect, B, occurs wholly within the Wilson River siltstone, the least stable unit in the study area. Cedar Creek runs around the toe of the slide, which was perhaps initiated by erosion of the base of a slope by the creek.

Based on vegetation growth and degree of dissection by streams, slide D appears to be the oldest, C next oldest, then A, with B appearing to be the youngest.

LINEATIONS

Numerous lineations, most apparent as straight river valleys and aligned streams, are seen throughout the study area. Mapping has shown that the largest and most prominent of these are the surface expressions of faults (see Figure 21). Some smaller scale lineations are found to be related to flow layering of the Wolf Point breccia and the Cedar Butte basalt. Northwest and southwest linear trends are the most common.

A very large series of circular lineations, 25 kilometers across, is located to the north of the study area (see Figure 20). It was found on topographic maps while doing lab-based reconnaissance prior to the actual field work. The perimeter is formed by the Nehalem, Salmonberry, North Fork of the Wilson and the main fork of the Wilson Rivers. Within this three-quarter circle are found smaller, concentric lineations formed by stream valleys and ridges. This pattern is mentioned here in hopes that other researchers will take an interest in and look more closely at this feature. Concentric lineations have been linked to volcanic centers or their associated intrusions (von Bandat, 1962) and this could represent the eruptive center of the Tillamook

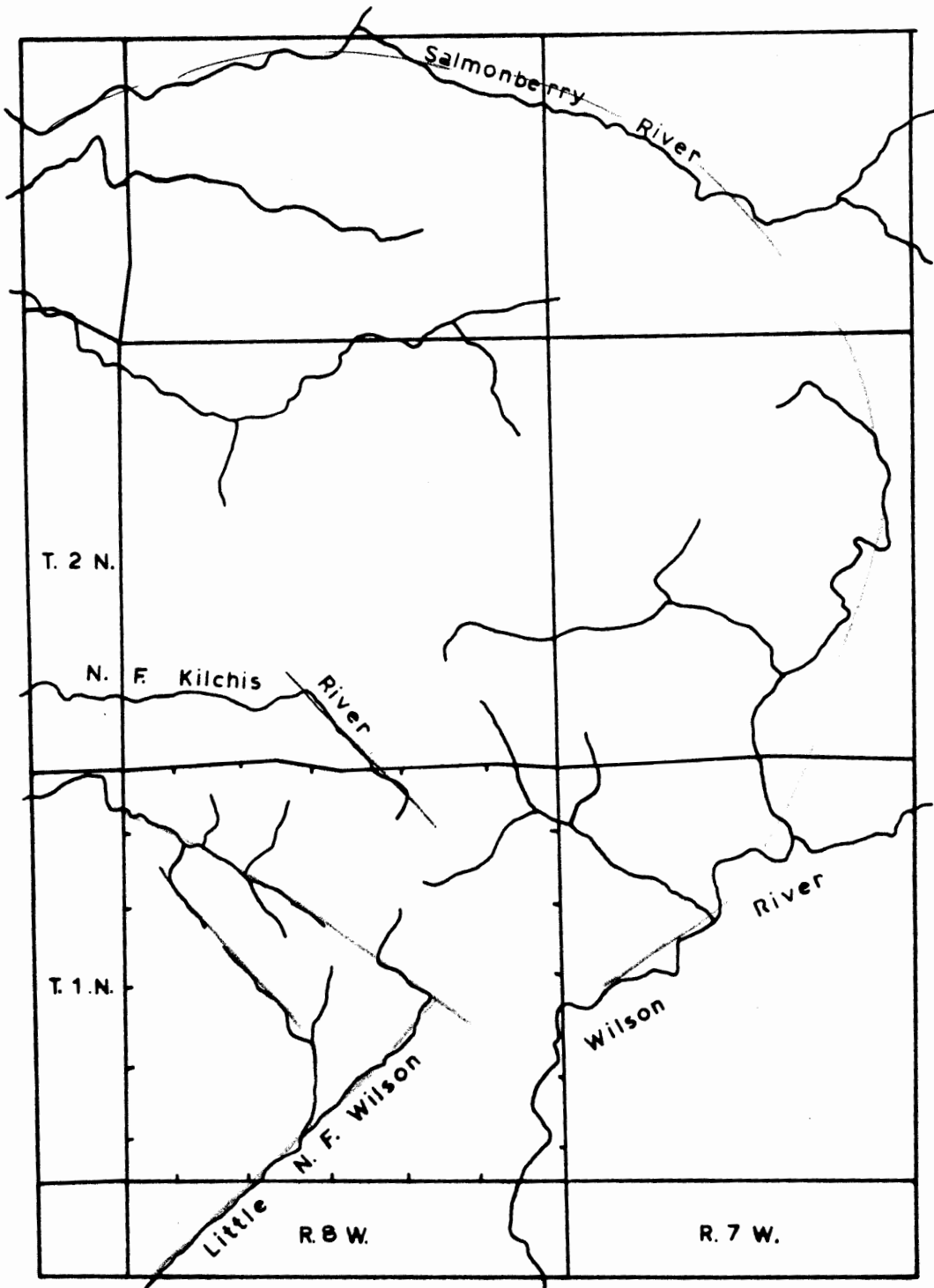


Figure 20. Lineation of river valleys in the Enright Quadrangle. Hatch markings indicate the study area boundaries.

Highlands.

STREAMS

Stream channels in the study area fall into two categories dependent upon the stream gradient. Waterways with high gradients are swept clean of channel debris during the spring runoff and therefore provide excellent views of the local bedrock. These streams are usually small and intermittent.

In the larger streams, the gradient is reduced and a vast amount of material collects on the valley floors (see Figure 22). Spring runoff rates are so much higher than normal rates that the material deposited each spring cannot be moved during the rest of the year. In places this material is of such depth that even the larger streams flow entirely within the alluvium and are seen on the surface only as occasional pools.



Figure 21. Looking across slide "A", (lower center) and down the northwest-trending fault-controlled valley of the Kilchis River. Note the faceted spurs on the left.



Figure 22. Typical large, low gradient stream (Little North Fork of the Wilson River) showing the great amount of bed load material and dense stream-side vegetation.

CHAPTER IV

STRUCTURE

INTRODUCTION

The structure of the study area is dominated by a regional dip of all units to the northwest. This is complicated by northwest and southwest trending vertical faults. Dikes with thicknesses over 1 meter have a preferred orientation of N30W which may be an indicator of the structural regime at the time of intrusion. Paleomagnetic data from the Cedar Butte basalt show that the basalts have rotated clockwise through 45° since their eruption (James McGill, 1979, personal communication).

REGIONAL DIP

Except for a fault-bounded block in sections 3 and 10, all units within the study area share a regional orientation which averages N40E 18 NW. Figure 23 shows the σ plot for all strike and dip measurements taken during the field season. While there is some variation, the clustering of the poles with a possible bi-modal distribution is obvious. With reference to Plate 1, it can be seen that the very low dip orientations which make up one of the bi-modal clusters are found along known faults and in the Wilson River siltstone near the contact with the Wolf Point breccia. Local sediment deformation may then be the cause of the very low dip cluster rather than structural manipulation. The other, higher dip cluster represents the regional average.

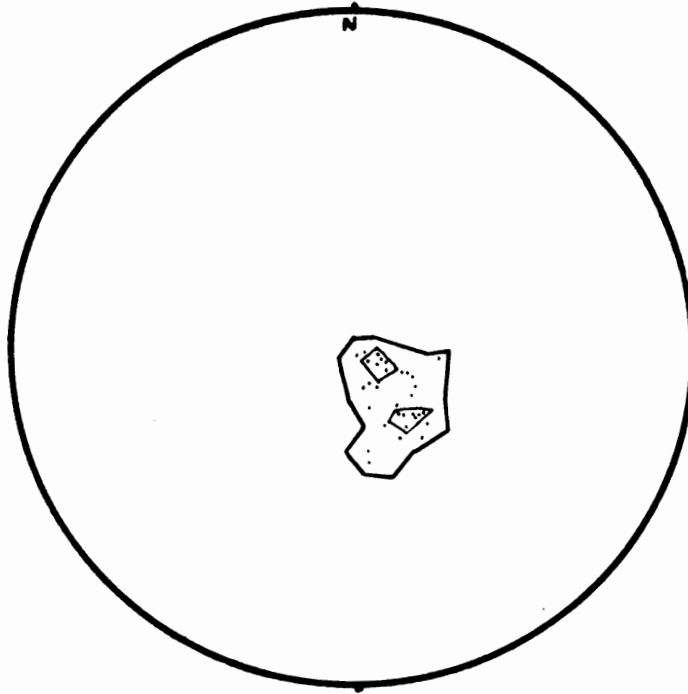


Figure 23. π_S plot of strike and dip measurements; $N = 35$.

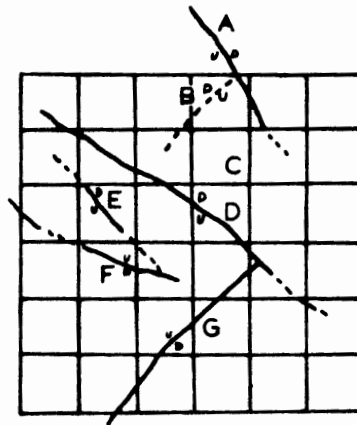


Figure 24. Fault location map.

FAULTING

At least three episodes of faulting are recorded in the rocks of the study area (see Figure 24). The first is represented by four faults, A, D, E and F, which all trend from N45W to N60W. All possess straight surface traces, which indicates that their fault planes are near vertical. Offset ranges from less than 50 meters on fault D to 425 meters on fault E. Fault D is also the longest in the study area, with a trace of 9.5 kilometers. Offset is always in a vertical orientation with no strike - slip component observed.

The second episode is seen in two faults, B and C, both of which trend approximately N35E. Both of these faults terminate on their north ends at one of the northwesterly faults. Once again, straight surface traces indicate a vertical fault plane orientation. Fault C has the greatest displacement observed in the study area. In sections 22 and 23 it has exposed a block of Meusial Creek diabase by displacing it upward 850 meters (see Plate 2, Cross Section B - B'). In both the northeasterly and the northwesterly faults, preferential erosion along the fault zone has produced visible topographic expression in the form of lineations (see page 54).

The third episode is seen in a single fault, C, which is the only one to trend east-west. Along with the faults A and B, it outlines a structural block in sections 3 and 10 (see Plate 1). This fault has not developed any topographic expression by weathering as have those of the first two episodes. A gouge zone 3 to 4 meters wide and composed mostly of clay can be seen in the SW $\frac{1}{4}$, NE $\frac{1}{4}$, sec. 10.

Within the structural block bounded by faults A, B, and C

described above, contacts between the units do not reflect the regional dip but instead tilt slightly (less than 10° , by measurement on the geologic map) to the south. Because of the noncontemporaneous nature of the boundary faults it is not plausible that this block simply remained stationary while the rest of the area assumed the regional dip. Instead, this block must have rotated into its present orientation after first taking on the regional dip. Then, structurally weakened by the junction of faults A and B, it rotated by breaking along fault C.

It is obvious that all faulting occurred after the cessation of volcanism for all units in the study area are faulted at least once. But determination of the order of the faulting episodes is based only on circumstantial and intuitional evidence. The key seems to be the termination of the northeasterly faults at their intersection with the northwesterly ones. With the much greater offsets seen in the northeast faults, their occurrence first would require them to be seen on both sides of the northwest faults. This is not the case; therefore, the northwest faults came first, followed by the northeast ones (see Figure 25).

The formation of the northeast faults caused movement of the fault blocks not only along the new faults but also along the plane of the pre-existing northwest fault. This accounts for the termination of the northeast faults; at the intersection movement and stress were diverted at right angles along the old fault plane.

The east - west fault occurred at some later time.

DIKE ALIGNMENT

Of the dikes included on Plate 1 (those with thicknesses of 1

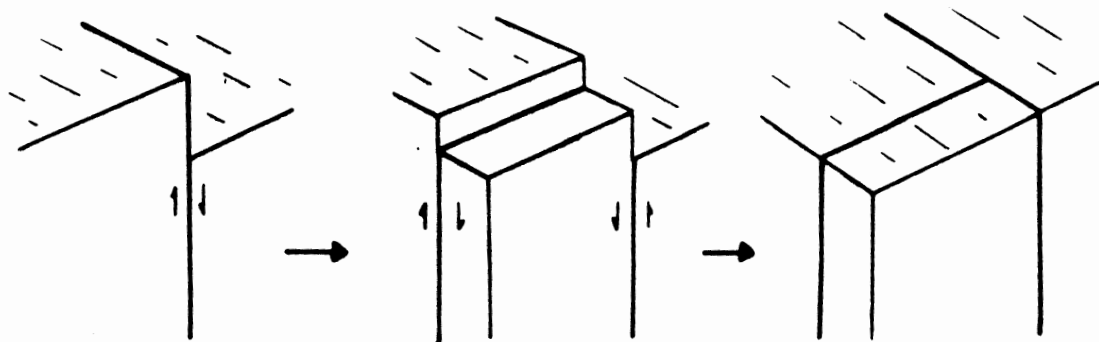


Figure 25. Block diagrams of the sequence of faulting episodes.

meter or greater), a majority show a preferred orientation of approximately N30W. Preferred orientation of dikes has been related to the stress field into which the dikes were intruded (Nakamura, 1977). In a compressional stress field, fractures used by intrusive rocks can remain open only if they are oriented parallel to the principal stress axis, σ_1 . In a tensional stress field, fractures are more common perpendicular to the tensional axis, σ_3 . This leads to the conclusion that at the time of the extrusion of the Cedar Butte basalt and the associated feeder dikes (40 to 45 million years ago) either a compressional stress field with a σ_1 orientation of N30W or a tensional field with a σ_3 orientation of N60E was in existence.

CHAPTER V

PALEONTOLOGY

INTRODUCTION

Both floral and faunal fossil remains are found in the sedimentary units of the study area. Animal fossils are common in the Wilson River siltstone, especially in the basal slate where metamorphism has hardened the rock, protecting the fossils from weathering and leaching. In the Wolf Point breccia the first sedimentary sub-unit contains numerous foraminifera tests and the second sub-unit abounds with plant remains and fish scales. Fossil identification was accomplished without the aid of a professional paleontologist and therefore scientific names will be limited to the generic level.

FAUNA

Represented in the fossil record of the study area are members of phyla Mollusca, Chordata and possibly Arthropoda. Trace fossils in the form of burrows are also present.

In the basal slates of the Wilson River siltstone are found most of the molluscs. The best collecting locality is located in a quarry about 200 meters to the east of the study area in the SW $\frac{1}{4}$, NW $\frac{1}{4}$, sec. 19, T. 1 N., R. 7 W. It is easily visible when traveling west on State Highway 6. Here can be found numerous examples of Glycimeris sp. (see Figure 26) with high, arching valves, pronounced radial ribbing and

various degrees of reticulate texture (Turner, 1938). One example of Acila sp. (Turner, 1938) was also found (see Figure 26), characterized by its distinctive "chevron" style of ribbing. Both of these molluscs inhabit medium to deep marine waters (Richard Thoms, personal communication) and show that these siltstones were laid down on the continental shelf or slope.

Numerous unidentifiable animal parts were also found in the rocks of the quarry. These include crushed (probably by lithostatic pressure) molluscan valves, individual fish scales, and bones, presumably of fish. Many of these bones are broken and found associated with masses of organic debris which are probably fecal pellets. Irregular pieces of chitinous material are also common (see Figure 26) and may be the remains of Arthropods. The chitin and fish bones range in color from brown to black, due primarily to carbon fixation as a result of the thermal metamorphism which produced the slate.

Animal remains are also found in the sedimentary beds in the Wolf Point breccia. In the sandstone of the first sedimentary sub-unit (see page 24), a thin section prepared for petrographic examination showed the presence of numerous foraminifera tests. An attempt to disaggregate the well-cemented sandstone to isolate the tests for identification was made using both the boiling water and kerosene method and a commercial solvent, "Quaternary 0." No usable specimens were recovered by either technique. Evidently the tests are so fragile from leaching that even the slight physical stress encountered in the disaggregation process is enough to cause destruction.

One animal burrow was also found in the sandstone, oriented parallel to the bedding. It has a round cross section 1 centimeter in dia-

meter and is 9 centimeters long (incomplete) and is filled with material slightly more coarse than the surrounding sandstone.

In the second sedimentary sub-unit (see page 24), the shale beds are very fossiliferous. Animal remains are dominated by fish scales. These scales are found on virtually every piece of shale examined. They range in size from 1 millimeter to over 1 centimeter across and are a clear amber in color. Preservation is detailed enough for growth rings and surface markings to be easily identifiable. Their incredible abundance cannot be fully explained; however, the copious ash falls which produced the shales might have decimated the local fish populations and caused scattering of the scales. One small pecten, 0.9 centimeters across, tentatively identified as Delectopectin sp. (Turner, 1938), a shallow water mollusk, was found in the shales. One animal burrow was also located (see Figure 26). It is oriented perpendicular to the bedding and is much smaller than the one from the first sandstone, being only 2 millimeters in diameter and 3.5 centimeters long (incomplete). However, its path is very contorted and the total length of the burrow may be as great as 6 centimeters. It is filled with very fine grained material.

The faunal remains suggest a moderate to deep marine environment for the lower portion of the Wilson River siltstone and a shallow water location for the upper portion of the Wolf Point breccia.

FLORA

No plant fossils were found in the lower portions of the Wilson River siltstone or in the first sedimentary sub-unit of the Wolf Point breccia. One fossil was located near the upper contact of the siltstone

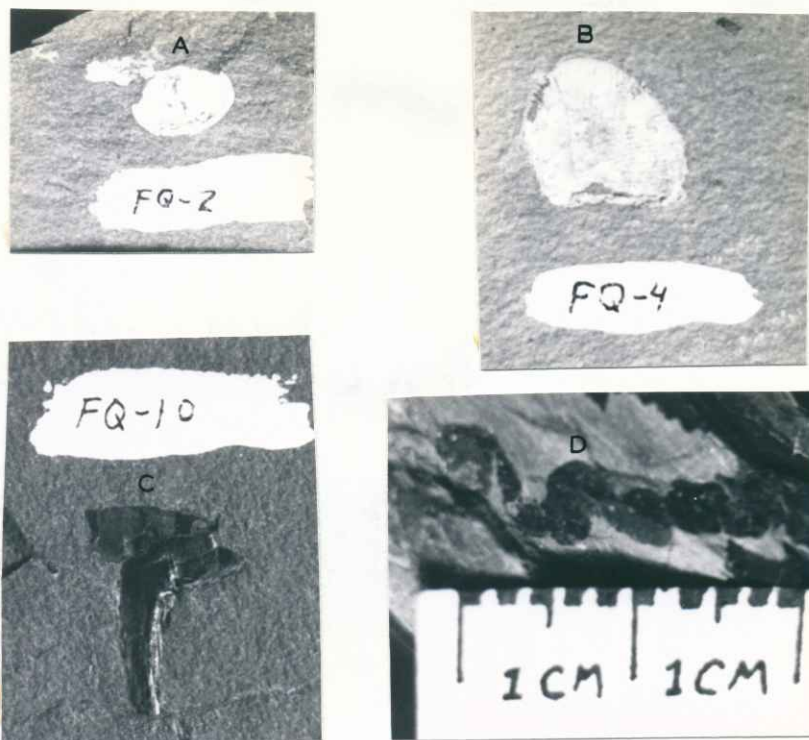


Figure 26. Representative faunal specimens; A - Glycimeris sp.; B - Acila sp.; C - chitinous fragment; D - animal burrow. Scale is equal in all photographs.

and floral remains are very abundant in the second sedimentary sub-unit of the breccia.

The one fossil from near the upper contact of the Wilson River siltstone (found in the SW $\frac{1}{4}$, SW $\frac{1}{4}$, sec. 13) is a seed of Juglans sp. (Bones, 1979), the common walnut (see Figure 27). It measures 2.4 centimeters wide by 3.2 centimeters long. A portion of the outer shell has broken away along the seam between the shell halves but no structure in the underlying seed is recognizable.

Floral remains are very common in the shales of the second sedimentary sub-unit of the Wolf Point breccia. Deciduous leaves and seeds, evergreen twigs and seeds, and reeds have all been identified. The most prolific collecting locality is in the SW $\frac{1}{4}$, NE $\frac{1}{4}$, sec. 14.



Figure 27. Seed of Juglans sp. (common walnut) from near the upper contact of the Wilson River siltstone.

Identified deciduous leaves include Platanophyllum sp. (Berry, 1930), an extinct sycamore-like tree, and Cornus sp. (Howard Schorn, personal communication), the common dogwood (see Figure 28). Numerous unidentifiable leaf fragments were found which at times were so abundant as to form leaf mats in the rock.

Seeds of Ailanthus sp. (MacGintie, 1953) and Picea sp. (MacGintie, 1953) were also found (see Figure 29). Ailanthus, known as the Tree of Heaven, became extinct in North America in the last half of the Tertiary but survived in China. It was re-introduced in the 19th century by Chinese laborers imported for construction of the railroads, and it now thrives in northern California. Picea is the common spruce.

Numerous examples of the twigs of the evergreen Chamaecyparis sp. (Berry, 1930), the false cypress or cedar, were found in the shales (see

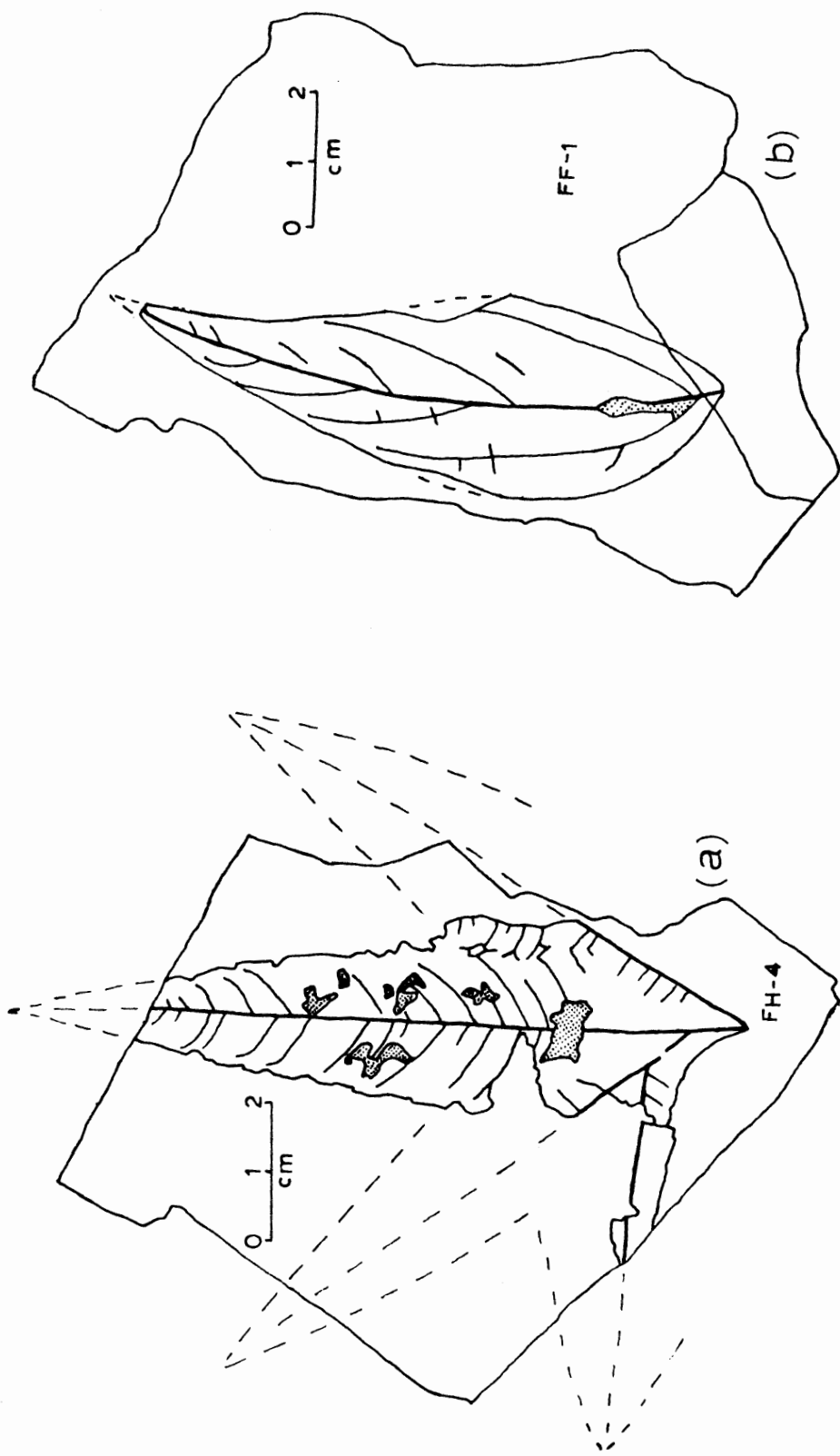


Figure 28. Drawing and reconstruction of Platanophyllum sp. (a) and Cornus sp. (b).

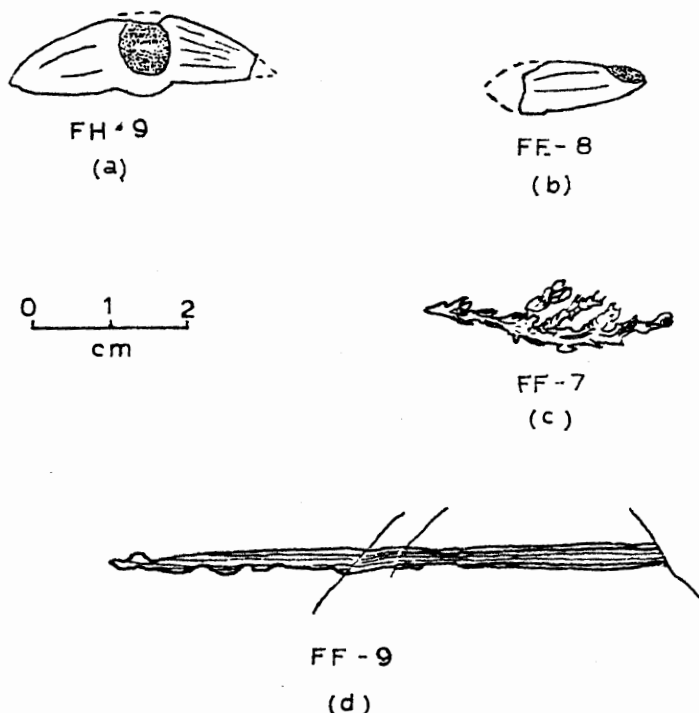


Figure 29. Drawings and reconstructions of: (a) Ailanthus sp. seed; (b) Picea sp. seed; (c) Chamaecyparis sp. ; and (d) Poacites sp. or Phoenicites sp.

Figure 29). The terminal ends of some twigs fall off after 3 or 4 years of growth, which explains the existence of whole twigs in the fossil record (Peattie, 1950).

Also fairly common is a reed, either Poacites sp. or Phoenicites sp. (see Figure 29), which lives in brackish to fresh water (Berry, 1930).

Size, completeness and abundance of the floral remains implies that not only was the material deposited in shallow water, but in near shore conditions. One would not expect a profusion of whole leaves to be deposited together if they were transported any great distance from shore. The presence of reeds also argues for shallow, near shore con-

ditions, perhaps even lagoonal.

The local climatic conditions as deduced from the floral assemblage is surprising. During the Eocene, Oregon is assumed, on the basis of the Clarno, Comstock and Goshen floras, to have been tropical or semi-tropical (Chaney, 1956). However, the spruce, cedar, dogwood, walnut and Tree of Heaven outline a temperate climate for the study area, perhaps similar to that which exists there now.

CHAPTER VI

GEOCHEMISTRY

INTRODUCTION

Major oxide geochemistry was obtained on ten samples picked as representative of the major rock types of the study area (see Table VI). The analyses were obtained from a commercial analytical laboratory which used a carbon arc spectrometry technique. Results of the analyses are listed in Table VII.

TABLE VI

IDENTIFICATION OF GEOCHEMICAL SAMPLES

KAC-40 . . .	Cedar Butte basalt
KAC-13 . . .	Cedar Butte basalt
KAC-00 . . .	Basalt dike
KAC-39 . . .	Basalt clast from Wolf Point breccia
KAC-19 . . .	Flow-equivalent of the Cedar Butte tuff
KAC-32 . . .	Meusial Creek diabase, chill zone
KAC-33 . . .	Meusial Creek diabase, massive zone
KAC-30 . . .	Meusial Creek diabase, diabasic zone
KAC-28 . . .	Litharenite, Wolf Point breccia
KAC-41 . . .	Arkose, Wolf Point breccia

TABLE VII

MAJOR OXIDE ANALYSIS OF REPRESENTATIVE SAMPLES

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	LOI*	Total
KAC-40	48.58	14.20	14.42	10.02	5.13	3.04	0.68	3.17	0.20	0.36	0.00	99.80
KAC-13	46.70	14.45	12.73	11.40	6.39	3.20	0.64	2.61	0.18	0.32	0.04	98.67
KAC-00	46.14	14.81	11.93	9.78	5.81	2.50	2.87	2.49	0.17	0.30	3.27	100.1
KAC-39	47.29	13.83	13.00	11.14	6.43	2.79	1.11	2.85	0.25	0.31	1.32	100.3
KAC-19	46.30	7.15	11.99	10.46	19.20	1.47	0.04	1.35	0.18	0.17	1.17	99.48
KAC-32	48.19	13.58	13.68	11.60	6.25	2.87	0.35	2.66	0.19	0.28	0.60	100.2
KAC-33	50.31	15.12	11.59	7.67	4.03	4.67	2.17	2.80	0.21	1.18	0.77	100.5
KAC-30	45.80	15.65	14.54	10.50	5.75	3.15	0.73	3.12	0.19	0.35	0.58	100.4
KAC-28	51.64	13.50	10.76	6.71	4.42	3.58	3.12	2.12	0.13	0.30	2.46	98.73
KAC-41	63.52	18.02	2.74	2.10	0.43	5.37	3.42	0.54	0.04	0.13	2.33	98.64

*Loss On Ignition

LOCAL CONSIDERATIONS

While not enough samples were analyzed to lend statistical validity to any conclusions drawn from the data, certain trends can be identified. The chemical compositions of the Cedar Butte basalt, the basalt dikes and the unaltered clasts from the Wolf Point breccia are nearly identical (samples KAC-40, KAC-13, KAC-00 and KAC-39). This lends credence to the hypothesis proposed earlier (see page 19) that the basalt and the breccia are part of the same eruptive episode and appear in their differing forms due to changing conditions of deposition, and that the basalt dikes represent the feeder conduits.

The flow-equivalent of the Cedar Butte tuff (sample KAC-19) exhibits a chemical signature markedly different from that of the basalt and breccia, with depressed Al_2O_3 , Na_2O and K_2O , and very high MgO amounts. Since the tuff is a lens-like unit within the eruptive episode of the Wolf Point breccia, it was assumed that it should be compositionally similar to the enclosing rocks. Petrographically, it is distinctive in its very high percentage of augite (see page 35). Chemical analysis of augite from the Coast Range (Snively et al, 1968) appears in Table VIII. Augite is found to contain significantly lower percentages of Al_2O_3 , Na_2O and K_2O and higher amounts of MgO than the basalt averages. With augite making up over half of the rock it is not surprising that the composition of the augite masks the whole rock composition.

Analysis of the Meusial Creek diabase gives confused, conflicting results. The chill margin (KAC-32) is very similar to the basalt and breccia flows but the chemistry changes in a non-recognizable manner through the massive (KAC-33) and diabasic (KAC-30) zones. The major

TABLE VIII
MAJOR OXIDE ANALYSIS OF AUGITE

	Cr-rich	Ti-rich
SiO ₂	50.7	47.3
Al ₂ O ₃	3.5	6.5
Fe (total)	5.5	8.2
CaO	21.1	20.7
MgO	16.0	14.1
Na ₂ O	0.34	0.53
K ₂ O	0.02	0.04
TiO ₂	0.88	2.0
MnO	0.13	0.15
P ₂ O ₅	0.0	0.0
	<u>98.17</u>	<u>99.52</u>

petrographic trends noticed in the diabase (see Figure 15) are an increase in plagioclase toward the center which is matched by an equal decrease in pyroxene. Plagioclase is rich in Al₂O₃ and CaO (Snively et al, 1968) but these oxides fail to show an increase in the chemical analysis. Augite, rich in Fe (total) and MgO, fails to form the expected depressed abundance of these oxides toward the core. The abundance of vapor phase minerals in the interior of the intrusion (see page 44) may account for the observed chemistry, but that is beyond the scope of this study.

The two sandstone samples were included to see how close an immature sediment will compare chemically to possible parent rocks. The

litharenite (KAC-28) was composed in large part of basaltic lithic fragments. Comparison of the analysis of the sandstone and the Cedar Butte basalt showed some similarities. The major discrepancy occurs in Fe (total), which may have been lost through oxidation, and the mobile ions CaO and MgO, which may be lost by solution. The arkose (KAC-41) does not resemble any rock type found in the study area but does compare satisfactorily to andesite - diorite rocks (Carmichael, 1974). Granitic rock fragments were found in the sedimentary rocks of the Wolf Point breccia (see page 29) and may in some way be related to the provenance of the arkose.

REGIONAL APPLICATIONS

Chemical analysis, in this case, is most useful for comparison purposes. To standardize results into easily readable form, analyses are plotted on a tertiary FMA diagram (see Figure 30). Studies have shown that lavas can be separated on the basis of their chemistry into tectonic setting (Pearce, 1977). The basaltic rocks of the study area cluster in that region of the diagram encompassing "continental lavas." Continental basalts have been hypothesized to form from partial melting or small scale rifting of a continental plate (Pearce, 1977). Noting that the basalts have rotated clockwise 45° , it is suggested that the basaltic magmas of the Coast Range formed as a result of continental rifting which continued after the extrusion to cause the observed rotation.

The lavas of the Tillamook Highlands are only one in a series of penecontemporaneous volcanic piles found within the Coast Range of Oregon and Washington. Analysis of basalt from two of these piles, the

TABLE IX
COMPARISON OF BASALTS OF THE COAST RANGE

	KAC-40	KAC-13	*older Siletz	*younger Siletz	*Crescent
SiO ₂ . . .	48.58 . . .	46.70 . . .	49.0 . . .	48.3 . . .	48.5
Al ₂ O ₃ . . .	14.20 . . .	14.45 . . .	14.5 . . .	14.6 . . .	14.6
Fe (total)	14.42 . . .	12.73 . . .	11.6 . . .	13.8 . . .	12.3
CaO . . .	10.02 . . .	11.40 . . .	12.2 . . .	11.5 . . .	11.8
MgO . . .	5.13 . . .	6.39 . . .	8.3 . . .	5.8 . . .	7.2
Na ₂ O . . .	3.04 . . .	3.20 . . .	2.3 . . .	2.6 . . .	2.6
K ₂ O . . .	0.68 . . .	0.64 . . .	0.17 . . .	0.14 . . .	0.22
TiO ₂ . . .	3.17 . . .	2.61 . . .	1.6 . . .	2.7 . . .	2.2
MnO . . .	0.20 . . .	0.18 . . .	0.19 . . .	0.25 . . .	0.21
P ₂ O ₅ . . .	0.36 . . .	0.32 . . .	0.15 . . .	0.31 . . .	0.26

*average of at least 8 samples

Crescent Volcanics of the Olympic Mountains area of Washington and the Siletz River Volcanics of Oregon, are given in Table IX and are also plotted on Figure 29.

As can be seen from the data, the basalts of the Coast Range bear a remarkable resemblance to one another. This is especially true for the basalts of the Tillamook Highlands and the younger Siletz Volcanics. It would seem that these lavas in some manner shared at least a common method of formation.

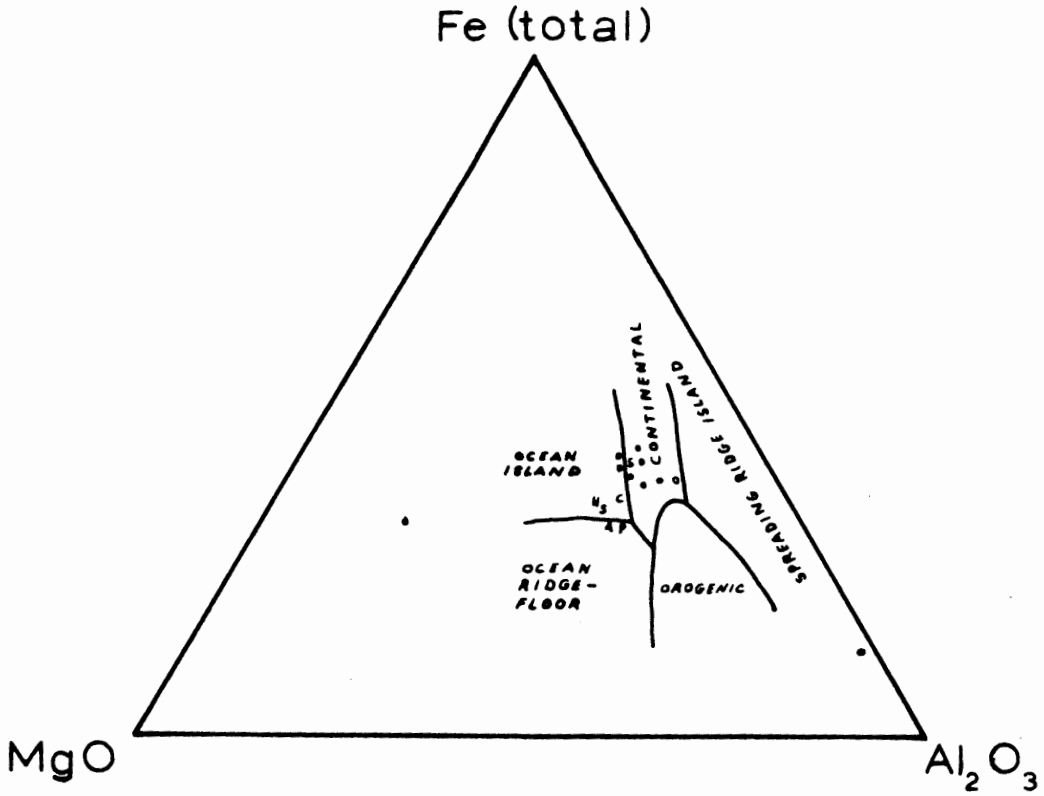


Figure 30. AMF classification of basalts. O - samples from the Tillamook Highlands; H - average composition of the Hawaiian Islands; S - average composition of the older and younger Siletz Volcanics; C - average for the Crescent Volcanics; A - average for the Atlantic sea floor; P - average for the Pacific sea floor.

CHAPTER VII

SUMMARY

The earliest record of events found in the study area is in the Wilson River siltstone. The very fine grained and rhythmically bedded nature of this unit tells of an off-shore, quiet water environment. Remains of Acila sp. and Glycimeris sp. indicate that the water was moderate to deep, possibly along the continental shelf or slope. These conditions may have existed for as long as 10 million years, given an average sedimentation rate of 1 centimeter/century, to form the 800 meters of observed thickness. At long intervals, turbidite flows from the south deposited thin beds of volcanic sandstone. The immature nature of the sands shows that they were not transported any great distance. Fish were abundant in the waters above the sediments and deposited fecal pellets while alive and scales and bones on their passing.

The sedimentary phase of the history of the study area ended with the onset of volcanic activity. Lavas extruded onto the sea floor were shattered by autobrecciation or phreatic brecciation. As these flows spread across the sea floor sediments, the underlying bedding was contorted or destroyed by the sudden increase in weight. In places, masses of the dense breccia sank into the soft substratum to form invasive pods and blocks. The start of the volcanic phase was not pervasive, but erratic. Over 100 meters of intercalated flows of breccia and layers of siltstone are found at the contact of the Wilson River siltstone and the Wolf Point breccia.

For the most part, flow breccia is the major rock type of the Wolf Point breccia. Higher in the unit, however, pillow lavas and hyaloclastites were deposited. Occasional solid cores are seen in the breccia flows, showing that as the thickness of the flow increased it would sometimes insulate the newly erupted matter, keeping it from shattering at contact with the marine waters.

At least twice the volcanic record is interrupted by sedimentary sub-units. The first, 100 meters above the lower contact, is represented by 10 meters of black, immature volcanic litharenite which may have been transported into the region by turbidity flows from a nearby volcanic island. The presence of animal burrows shows that the volcanic activity ceased long enough to allow expansion of infauna into the area.

After another period of volcanic activity, the second sedimentary sub-unit, located 350 meters below the upper contact, was deposited in the form of 25 meters of immature feldspathic litharenite and tuffaceous shales. There is a plethora of fossil material preserved in the shales. This material consists mainly of whole leaves and other plant debris. Leaves of the dogwood and an extinct sycamore, twigs of cedar and seeds of the spruce and Tree of Heaven tell of a nearby land mass sporting a temperate climate. Whole leaves are not generally transported great distances en masse, which perhaps indicates that by this time some portions of the Tillamook Highlands had already risen above the level of the sea and developed a floral cover.

Whole leaves are also not generally found in deep water sediments. This would indicate that by this time the deposition of the Wilson River siltstone and the Wolf Point breccia had raised the floor of the ocean

to very near the surface. At least 1200 meters of material separates the medium to deep water mollusks from the shallow water leaves, too much to be accounted for by simply piling deposits on the continental shelf. Some subsidence was probably going on to allow this thickness of material to accumulate.

The evidence of a local temperate climate poses a problem. It is widely accepted, on the basis of contemporaneous flora such as the Clarno, Goshen and Comstock, that at this time Oregon sported a tropical to semi-tropical climate. With the nearest contemporaneous subaerial deposits near the site of the present Cascade Range and marine deposits in the intervening area, the Tillamook Highlands seem to have existed as an island well off shore. So situated, the surrounding oceans would act as a large heat sink, and, possibly helped by south-flowing cold currents from the north, a localized temperate climate could have existed off shore while a tropical climate dominated the mainland.

Higher in the Wolf Point breccia was erupted the lens-like body of the Cedar Butte tuff. It was worked by the shallow waters and grades laterally both in bedding thickness and grain size. Surprisingly, it is chemically different from the surrounding breccia. The deviant chemical signature can be explained by the large percentage of augite crystals, up to 50 percent, in the tuff. If an increase in augite content can account for the chemical discrepancy, then a mechanism for the augite increase must be found.

In a region in which homogeneous, large scale volcanism was occurring, it is not reasonable to assume that a second, contemporaneous magma source was present. The tuff must have come from the same source as the regional material. Again, the presence of the large, euhedral

augite crystals presents a solution. Augite is present in all the eruptive rocks of the study area as small, subhedral to euhedral crystals. It is possible that the very large crystals found in the tuff settled to the lower portions of the magma chamber due to their size and mass. This would form a crudely layered chamber, with the lower regions containing larger and more numerous crystals. Eruptions from the upper portions of the chamber produced the breccia and basalt flows while the tuff was produced by tapping the lower regions.

The submarine breccia finally built up to the level of the sea which permitted the extrusion of the subaerial Cedar Butte basalt. Some isostatic settling of the region or eustatic rise in sea level occurred at this time, for at least 100 meters of intercalated breccia and basalt, too much to be accounted for by the diurnal tides, was deposited before the subaerial basalts became predominant.

With the eruption of at least 900 meters of basalt, the depositional history of the study area was over. With the nearest contemporaneous subaerial deposits near the present site of the Cascade Mountains, the Tillamook Highlands seem to have existed in the late Eocene as a volcanic island well separated from the mainland.

Feeder dikes for the breccia and the basalt, at least those over 1 meter thick, are aligned roughly N30W. There is a general consensus among researchers of the tectonic evolution of western North America (Atwater, 1970; Simpson, 1977) that during the Eocene an active subduction zone existed along the western boundary of the North American plate. The presence of such a subduction zone would place the entire region, including the study area, under compressional stress. By making σ_1 parallel to the dike orientation, N30W, and then rotating counterclock-

wise 45° to eliminate post-intrusion movement as seen in the paleomagnetic data, the subduction zone can be seen to require an axis orientation of N15E.

At some as yet undetermined time, the study area, specifically the Wilson River siltstone, was invaded by the sill-like Meusial Creek diabase. The heat from this intrusion baked the siltstones into slate within 20 meters of the contact. Transference of this heat from the sill chilled its outer portions, forming a chill margin of abundant glass up to 100 meters thick. This glass formed an impermeable barrier to the exsolving volatiles from the inner portions of the intrusion, creating mineral assemblages usually associated with weathering. Cooling of the magma produced columnar joints up to 100 meters into the body of the sill. As crystallization proceeded toward the center of the sill, mineralogical trends evolved; plagioclase becoming more sodic and constituting a greater percentage of the rock and augite becoming less prominent. Apatite and olivine appear in the core. The very last liquid solidified in the cracks and fractures of the core as streaks of micropegmatite.

The study area had undergone no major structural deformation during its depositional history. It now assumed a regional dip of 18° to the northwest and was broken first along northwest-trending faults, then along northeast-trending faults, and finally a large block around Cedar Butte rotated back to near horizontal by breaking along an east-west fault. During all of this, the entire area was rotating through 45° .

The Tillamook Highlands then underwent a long period of erosion, forming the steep-walled canyons of today. It withstood fires which

denuded the slopes of vegetation and, with the coming of the winter rains, most of the soil cover. All of this eventually culminated with a slightly perplexed student wandering through a small portion of the southcentral edge of the Highlands trying to fathom what had gone on before.

FINIS

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