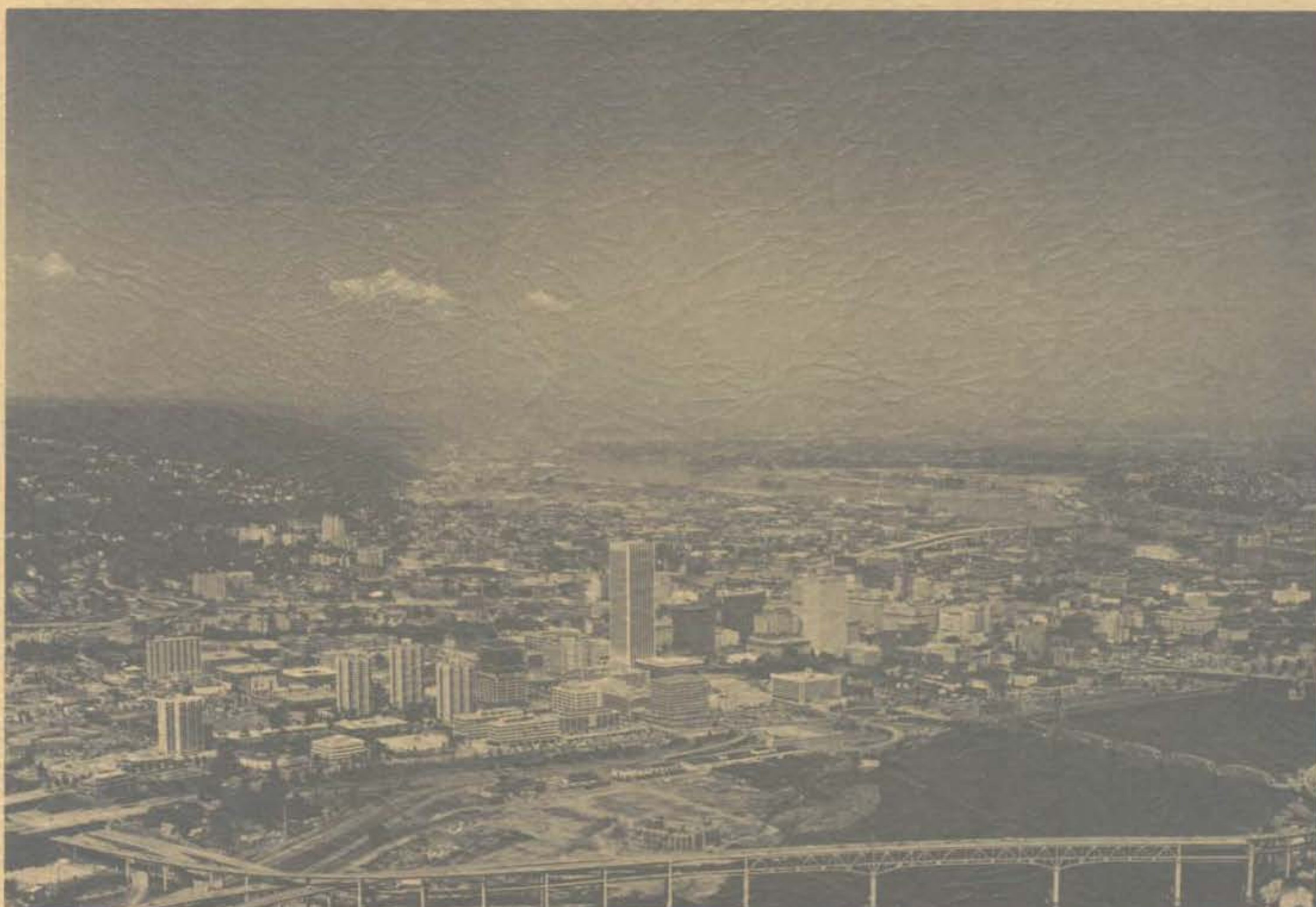
BULLETIN 77

GEOLOGIC FIELD TRIPS in NORTHERN OREGON and SOUTHERN WASHINGTON



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GEOLOGIC FIELD TRIPS

IN NORTHERN OREGON AND SOUTHERN WASHINGTON

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Field Trip Committee Chairman

for the

GEOLOGICAL SOCIETY OF AMERICA
Cordilleran Section Meeting
Portland, Oregon March 1973

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PREFACE

The geology of Oregon is as varied and fascinating as that of any state of the Union. East of Portland lies the north-south trending Cascade Range, a snow-capped volcanic pile. Farther east lie flood basalts, batholithic highs, and Basin and Range terrain. West of the Cascades the interaction of land, sea, and volcanism has left a challenging geologic record.

In tune with geologic developments around the world, the plate tectonic model is finding increasing application to the geology of the State of Oregon. The imbricate thrust complex of Mesozoic rocks in southwestern Oregon has been attributed to sea-floor spreading, and recently the enigmas associated with the Colebrooke Schist have begun to yield to analysis in terms of the "new tectonics." Recent work in the Tertiary units about the periphery of the Klamath Mountains may soon lead to an even more accurate appraisal of the age and nature of the later stages of plate tectonic activity in that area. Closer to home, the Coast Range is largely unmapped and is ripe for reinterpretation in terms of the new tectonics.

The fault blocks, basalt flows, and ignimbrites of southeastern Oregon are undergoing re-evaluation in terms of some of the subtler aspects of sea-floor spreading. Tensional shearing related to deep-seated upwelling may account for the tapping of basaltic magma at depth and for the regional development of block faulting. Similar mechanisms may account for the extensive flood basalts of the Columbia River Group to the north. Both may be part of a larger picture in which late Miocene re-orientations of plate tectonic features profoundly affected the geology of much of the Pacific Basin and the world.

Going back in time, the early and middle Tertiary andesites of the Cascades Range and the John Day Basin may be interpreted as volcanic material produced by differential melting of a lithospheric plate related to an ancestral Pacific Basin rise system. Still further back in time, many of the Paleozoic exposures of northeastern Oregon may represent structural slabs of oceanic rock brought together in a subduction zone by sea-floor spreading. Viewed in this light, our failure to relate the various units stratigraphically is not only understandable, it is to be expected. With the present day stratigraphic techniques, perhaps our aim should be to understand the structural relationships of the units and to reserve final stratigraphic synthesis until later.

Practical use of the geologists' knowledge of Oregon is increasing as cities and counties become more aware of the influence of mass movement, seismic activity, and ground water on urban development. Similarly, various governing bodies and segments of private industry are integrating more and more geologic data into their planning process. Concern for ecology is foremost in the minds of the people, and a knowledge of geology is basic to an understanding of the environment.

Geology in Oregon has outgrown its historical role as just a basic tool of research and production for the mineral industry, although this will always be one of its important functions. Geology in Oregon today is an integral part of land-use planning, energy resource appraisals, power plant siting, and water management. It is responsible for the body of knowledge which surrounds a potential new source of almost pollution-free power within the state - geothermal steam.

As shown by the variety of the field trips presented here, it is evident that there is room in Oregon for specialists in all aspects of geology. Field Trip 1 views the Cretaceous marine strata and Tertiary volcanic and volcaniclastic deposits of central Oregon. Field Trips 2 and 3 respectively investigate the early Tertiary and middle Tertiary records of western Oregon. Trips 4 and 6 are aimed primarily at the geology of the Columbia River Group and associated units. The former studies the geology of the Columbia River Gorge; the latter concentrates on some of the newer techniques of individual flow recognition. Trip 5 is a tour of the urban geology of the Portland area, and Trip 7 is an unguided tour of the lava caves of nearby Mount St. Helens in Washington.

John Beaulieu, Stratigrapher
Oregon Department of Geology and Mineral Industries

FIELD TRIP NO. 1

CRETACEOUS AND CENOZOIC STRATIGRAPHY OF NORTH-CENTRAL OREGON

HUDSPETH AND GABLE CREEK FORMATIONS
Keith F. Oles
Oregon State University

CLARNO GROUP
Harold E. Enlows - Keith F. Oles
Oregon State University

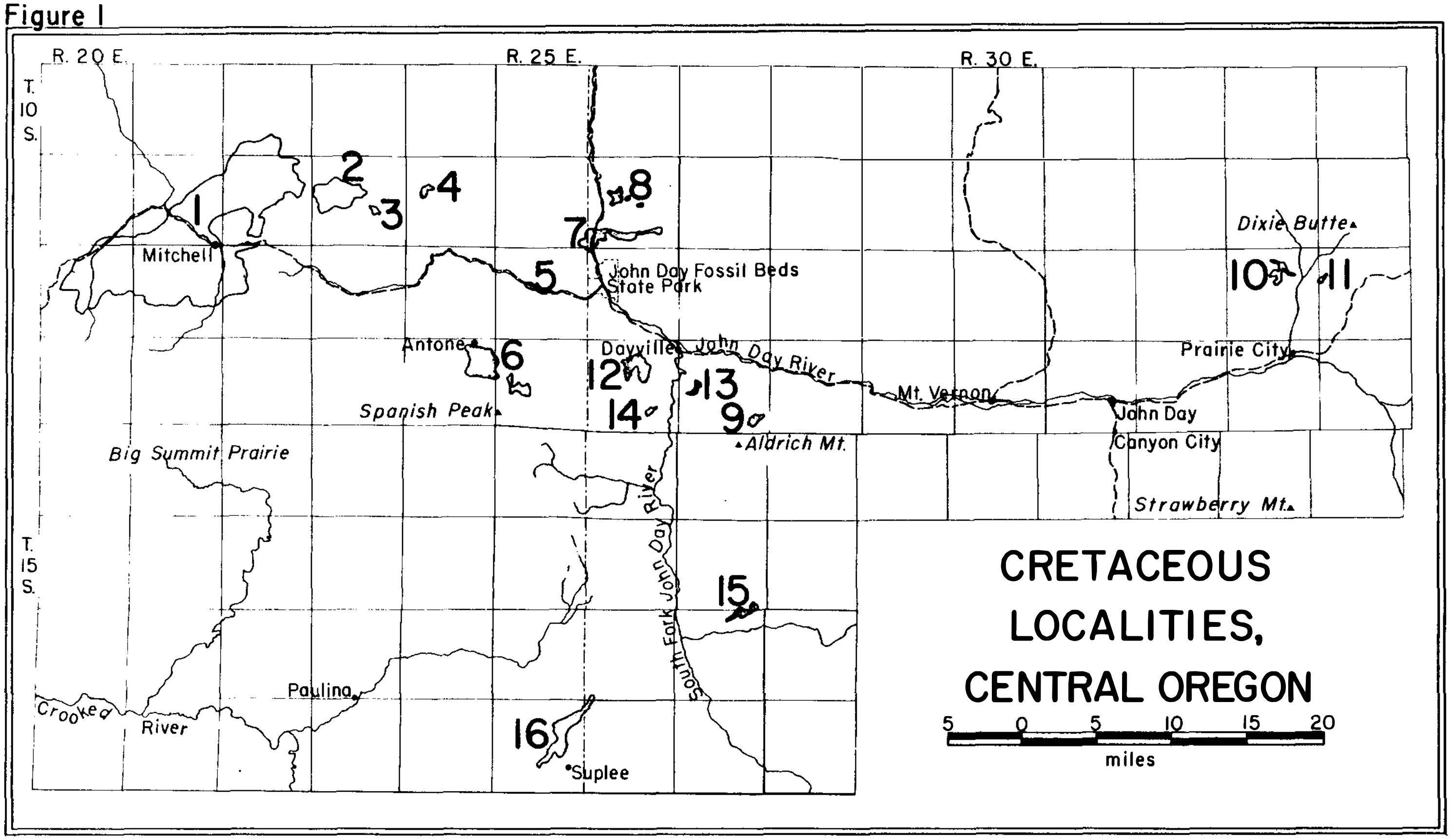
JOHN DAY FORMATION AND COLUMBIA RIVER BASALT
Paul T. Robinson
University of California, Riverside

MASCALL AND RATTLESNAKE FORMATIONS
Harold E. Enlows
Oregon State University

GEOLOGY OF THE DESCHUTES BASIN
Edward M. Taylor
Oregon State University

March 1973

Figure I



1 – Mitchell 2–Bearway Meadows 3 – Foppiano Creek 4–Waterman Flat 5–Mountain Creek 6–Antone 7–Goose Rock 8–Big Basin
9–Aldrich Mtn 10–Bull Run 11–Ricco Ranch 12–Battle Creek 13–Dexter Ranch 14–Tunnel Creek 15–Round Cr. 16–Bernard Rch

Figure 1. Cretaceous localities, central Oregon.

HUDSPETH AND GABLE CREEK FORMATIONS

Keith F. Oles

Introduction

Within the complex of ranges and highland areas of central Oregon--a region described as the Blue Mountains section by Thornbury (1965)--there are at least sixteen localities where Cretaceous marine and continental rocks crop out. In an area of approximately 2,500 square miles--from as far east as Dixie Butte near Prairie City, as far south as Suplee, and as far west as Mitchell (Figure 1)-- these Cretaceous rocks occupy geographically isolated pockets ranging from a few acres to scores of square miles in extent. Dominating part of this region is a sequence of east-west-trending ranges including the Ochoco Mountains and the Strawberry Mountains; a majority of the Cretaceous localities lie north of these ranges. Of these outcrop areas, the most extensive by far is that lying in the vicinity of Mitchell [1]. Here, marine and continental sedimentary rocks of Albian and Cenomanian age crop out over more than 70 square miles. The sequence, more than 9,000 feet thick, lies with angular unconformity on Permian metasedimentary rocks, and is overlain unconformably by Tertiary lavas and volcaniclastic sedimentary rocks. The Cretaceous rocks have been folded, complexly faulted, and disrupted by numerous fault-controlled and randomly oriented intrusions of Tertiary age.

The Cretaceous rocks are divided into two intertonguing formations. One, a widespread and thick sequence of marine mudstones, with subordinate siltstones and sandstones, is the Hudspeth Formation. Intertonguing intricately with these marine rocks are the fluvial and deltaic conglomerates and sandstones of the Gable Creek Formation. The total sequence consists of the Basal Member of the Hudspeth Formation, a thin sandstone and conglomerate unit lying unconformably upon the Permian basement rocks; a thick mudstone and siltstone unit designated the Main Mudstone Member of the Hudspeth Formation; and twelve conglomerate and sandstone members of the Gable Creek Formation intertonguing with a like number of mudstone and siltstone units of the Hudspeth Formation. Shapes of tongues, textural and thickness variations, and primary sedimentary structures show that during middle Cretaceous time there was a rising land mass on the north. Very large volumes of coarse sediment apparently were delivered by major rivers to a shallow marine embayment, and extensive alluvial piedmont and delta plains projected into this sea. Swinging distributaries, episodic uplift of the source areas, and intermittent subsidence of the basin caused the shoreline to fluctuate and produced a complex intertonguing of fluvial-deltaic and marine sediments.

The descriptions that follow have been largely abstracted or paraphrased from two publications: an article in the American Association of Petroleum Geologists Bulletin (Wilkinson and Oles, 1968), and Bulletin 72 of the Oregon State Department of Geology and Mineral Industries (Oles and Enlows, 1971), which includes a geologic map of the Mitchell quadrangle.

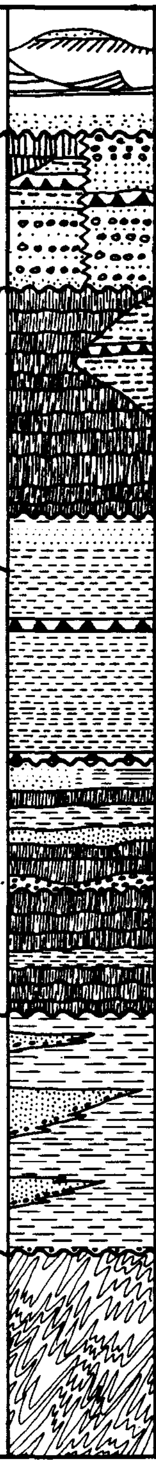
Stratigraphy

Basement rocks

The oldest rocks in the Mitchell area are metasediments of latest Paleozoic age (Table 1). They are exposed mainly at two localities. The smaller of these outcrop areas, lies in the vicinity of Meyers

[1] Mitchell quadrangle, 30' series, 1926; Mitchell quadrangle, 15' series, 1966, and Lawson Mountain quadrangle, $7\frac{1}{2}$' series, 1968.

Table 1. Composite stratigraphic column, central Oregon.



Period	Epoch	Unit	Symbol	Thickness	Description	millions of years
QUAT.	Pleistocene	Quaternary deposits	Qal Qls Qfg Qb	variable	Valley fill and flood-plain deposits; extensive landslide areas; remnants of high, older fans; basalt flows	
TERTIARY	Pliocene	Deschutes Formation ~ Rattlesnake Formation	Td / Tr	0-800'±	Td: Volcanic siltstones, sandstones, conglomerates; many intercalated basalt flows, ignimbrites Tr: Volcanic conglomerates and sandstones; a widespread ignimbrite	4.7 6.4 12.0
	Miocene	Columbia River Group Mascall Fm.	Tm Tcr	Tcr: 1,000'± Tm: 2,000'±	Tcr: Thick basalt flows; Yakima above, Picture Gorge below Tm: Fine-grained volcanic sediments; local diatomite, ignimbrite	14.0 18.0
	? Eocene – Oligocene	John Day Formation	Tjd	0-4,000'	Varicolored fluvial and lacustrine tuffs, sandstones, conglomerates; ignimbrites Tir, Tid: Various leucorhyolite and dacite intrusions	25 30–36?
		Clarno Group: Upper	Tct$_2$ Tcmf Tcf$_2$ Tcva	2,000'±	Andesite flows, mud flows, lacustrine and fluvial tuffs from local vents; in Mitchell area mainly from Keyes Mtn.; vent agglomerate	
		Clarno Group: Lower	Tcf$_1$ Tct$_1$ Tcvb	4,000'±	Thick andesite flows; varicolored tuffs; local volcanic breccias. Tia, Tib: andesite and melabasalt intrusions	46
CRETACEOUS	Albian – Cenomanian	Gable Creek and Hudspeth Formations	Kgc Kh	9,000'+	Fluvial-deltaic Gable Creek sandstones and conglomerates (11 members) intricately intertongued with marine Hudspeth mudstone, siltstones, thin sandstones (12 members plus a basal unit - Khb)	100 106
PERMIAN	Wolfcampian(?)	Metasediments	Pms	?	Phyllites, cherts, and crystalline limestones - metamorphosed marine sedimentary rocks.	230 ?

Table 2. Properties of tongues, Gable Creek and Hudspeth Formations

Factors	Gable Creek Fm.	Hudspeth Fm.
Lithology	Conglomerate and sandstone, minor siltstone and mudstone	Mudstone, siltstone, minor thin sandstone beds
Shape	Wedge shape or tongues; locally discontinuous	
Thickness	Range 0 at terminations to 700 ft. for tongue 9; tendency: thin or wedge out southward	Range 0 at terminations to almost 3,000 ft. for Main Mudstone Member; tendency: thin or wedge out northward
Terminations of tongues	Abrupt: complex intertonguing and facies changes produce terminations generally within 1 mile distance along strike	
Bedding	Laminated fine-grained rocks to 25-ft. thick conglomerate beds	Laminated to 4-inch sandstone beds
Textures	Very fine-grained sandstone to boulder conglomerate. Tendencies: finer grained upward, progressively finer grained southward	Mudstone, siltstone, with minor very fine- to coarse-grained sandstone. Marked changes along strike to coarser clastic rocks at terminations of tongues
Basal contacts	Sharp; erosional and disconformable	Conformable and gradational
Sedimentary structures	Scour-and-fill, cross-bedding dominant; graded beds common; lensing sandstones common; local ripple marks, mud cracks, planar orientation of pebbles; scarce load casts and imbrication	Prevailingly laminated; local scour-and-fill, cross-lamination or-bedding, mud cracks; load casts common in lensing sandstones; flute casts locally
Fossils	Scarce; generally only plant debris; local coaly blebs; pelecypods in upper transition zones	Locally abundant ammonites; rare sandy zones contain echinoids, ammonites, fish teeth, plant debris; local worm tubes, gastropods

Canyon (SW ¼ sec. 13 and NE ¼ sec. 23, T. 11 S., R. 21 E.). Here, in the steep walls of Meyers Canyon and a parallel tributary immediately south, are exposed about 60 acres of phyllites and subordinate crystalline limestones. In the center of the outcrop is an interesting occurrence of blue schist. The metamorphic rocks stand nearly vertically, are intensely deformed, and have numerous isoclinal and sub-isoclinal folds. Quartz boudins are common to the crestal areas of the folds.

The crystalline limestones crop out in pods and lenticular masses up to 50 feet in length or in long stringers within the enclosing phyllites. The pods appear to be tectonically dislocated lenses of former limestone beds. Fusulinids, too poorly preserved to permit generic identification, have been collected from the limestones by Dr. David A. Bostwick [(2)]. The sizes and shapes of the fusulinids suggest a Permian age, and they resemble Early Permian forms found in the Coyote Butte Formation in the Grindstone Creek area 45 miles to the southeast.

The larger of the main basement outcrop areas lies farther to the northeast in the vicinity of Tony Butte. About two square miles of the older rocks are exposed in parts of secs. 34, 35, and 36, T. 10 S., R. 22 E.; secs. 1, 2, 3, and 12, T. 11 S., R. 22 E.; and secs. 6 and 7, T. 11 S., R. 23 E. The major lithic types are phyllites, crystalline limestones, and cherts.

Cretaceous rocks

Summary of the section: The total sequence can be described in the following generalized terms (Figure 2). First, the Basal Member of the Hudspeth Formation is a thin (76 feet at Meyers Canyon) sandstone and conglomerate unit which lies with angular unconformity on the Permian metasedimentary rocks. Solution and honeycomb weathering of the Permian limestone masses resulted in depressions which later were filled by sands of the Basal Member. Directly overlying the eroded metamorphic rocks is a basal sandstone which includes subangular to subrounded pebbles and cobbles of chert, limestone, and phyllite, apparently derived from the underlying rocks. Succeeding the basal conglomeratic sandstone is a sequence of sandstones and thin conglomerate beds.

Transitional above the Basal Member is a very thick (2,897 feet along the principal reference section) mudstone and siltstone unit, the Main Mudstone Member of the Hudspeth Formation. Thence upward in the section there are an additional twelve tongues of the Hudspeth Formation and twelve tongues of the Gable Creek Formation. The youngest Cretaceous rocks exposed in the area belong to Hudspeth tongue 12. Cropping out only in secs. 5 through 8, T. 12 S., R. 22 E., these marine rocks are overlain unconformably by the Tertiary Clarno Formation.

Age of Cretaceous rocks: The Cretaceous strata range in age from early Albian to Cenomanian. These dates are based on faunal suites of ammonites and pelecypods. Fossil determinations have been made by Anderson (1938, 1958), Jones and others (1965), and Packard (1928, 1929, personal communications 1969, 1970). The bulk of the section apparently is Albian in age. However, in Gable Creek tongue 11, in the Johnson Creek valley, *Trigonia* sp. have been collected which correlate with Cenomanian forms described by Packard from the Antone locality farther to the southeast. For a description of some of the faunas which have been described up to 1960, the work of Popenoe and others (1960) is very helpful.

Cretaceous Paleogeography

In the search for criteria helpful in paleogeographic reconstruction, the coarser clastic rocks of the Gable Creek Formation and the intercalated sandstones of the Hudspeth Formation yield the most data. The conglomerates and sandstones return the most information on provenance and depositional environments. The mudstones and siltstones of the Hudspeth Formation, which compose up to half of the total sequence, exhibit fewer environmental signatures.

A description of some of the properties of the rock units follows (Table 2).

[(2)] Department of Geology, Oregon State University, Corvallis

Shape of outcrop area

The area of outcrop of Cretaceous rocks in the Mitchell and Lawson Mountain quadrangles is elongate, being more than 22 miles along strike, northeast to southwest. North of the east-west-trending Mitchell fault the maximum outcrop width across the strike is about 5 miles, whereas south of the fault the width is up to 12 miles. As a result of deep dissection the discrete members of the two formations are discontinuous; moreover, faulting, intrusions, and unconformable overlaps by Tertiary strata conceal or obscure much critical paleogeographic information (Figure 3). Although the area is limited in size and continuity, the Mitchell anticline--the major flexure of this area--does afford a three-dimensional view in that several members are present on both flanks of the fold and can be correlated across the axis. This, coupled with multiple observations along strike, indicates that the members of the two formations are wedge-shaped and can be designated as tongues.

Within the upper part of the Cretaceous sequence seven tongues of the Gable Creek Formation (tongues 1, 2, 4, 5, 7, 8, and 10) wedge out southward into the marine facies of the Hudspeth Formation. The other five Gable Creek members thin markedly and become finer grained southward. In obverse manner, four Hudspeth members (tongues 2, 3, 6b, and 8) wedge out northward into the Gable Creek Formation (Figure 4). Most of the other Hudspeth tongues are truncated at the major east-west-trending Mitchell fault. However, all thin markedly northward.

Observations along Gable Creek tongues show that the loss of thickness is accomplished principally through repeated lateral facies changes at the bottom of each unit. The mechanism results in a southward thinning of the total sequence as, successively, the bottommost conglomerate beds transitionally and laterally pass into sandstone and siltstone, ultimately to merge with the siltstones and mudstones of the Hudspeth Formation. This is a typical regressive relationship with continental and nearshore sediments extending basinward over penecontemporaneously deposited finer-grained marine detritus.

Textural changes within Gable Creek tongues

Textural changes within each Gable Creek Member are considered in both a vertical and a lateral, along-strike context. Vertically, despite multiple sedimentation units with normal, reverse, and double grading, and the intercalation of lensing sandstones, there is a gross tendency for the sizes of the dominant clastic particles to decrease upward within a tongue. This pattern culminates upsection with the sandstone beds at the top of each tongue in a transition zone grading upward into the siltstones to mudstones of the overlying Hudspeth member. This is a typical transgressive relationship, the finer grained marine sediments extending shoreward over coarser grained deposits, and is indicative of a reversal in the depositional or sea level conditions which pertained during the prior regression.

Laterally each Gable Creek tongue becomes finer grained southward, most noticeably where the tongue wedges out into mudstone. Even tongues which do not actually terminate within the outcrop area, but thin markedly southward, show a pronounced decrease in grain size. Several, most notably tongue 11, have changed transitionally to sandstone as the predominant rock type at the southwestern extremity of outcrop.

Basal contacts of Gable Creek tongues

Coarsely clastic tongues of the Gable Creek Formation invariably have a non-transitional, disconformable, sharp basal contact with the underlying Hudspeth mudstones and siltstones. These sharp contacts, locally of a demonstrable scour-and-fill character, indicate erosion of finer grained detritus immediately below the Gable Creek tongue. Thus sediments of the Hudspeth Formation have been eroded at the base of each Gable Creek member, but the thickness of sediment removed at each depositional interface is not definable.

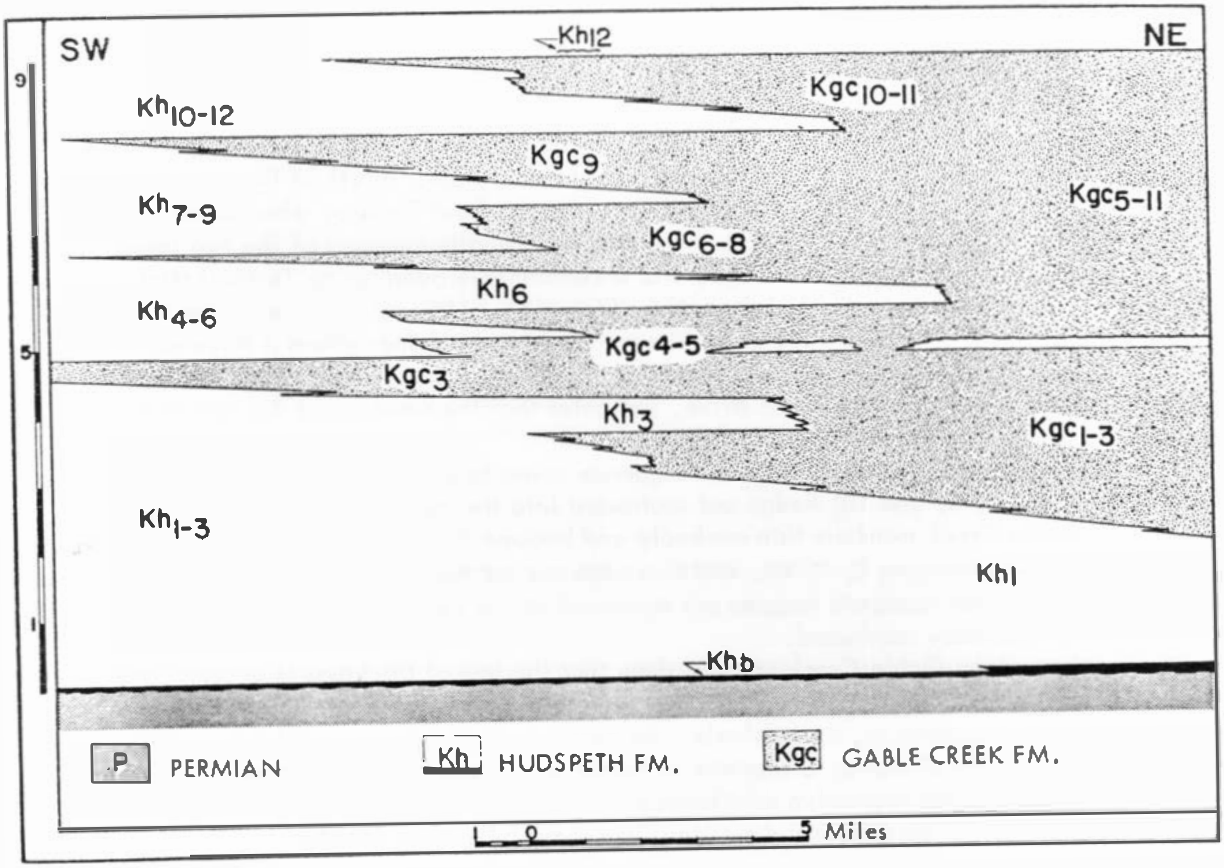


Figure 2. Schematic diagram of intertonguing Hudspeth and Gable Creek Formations.

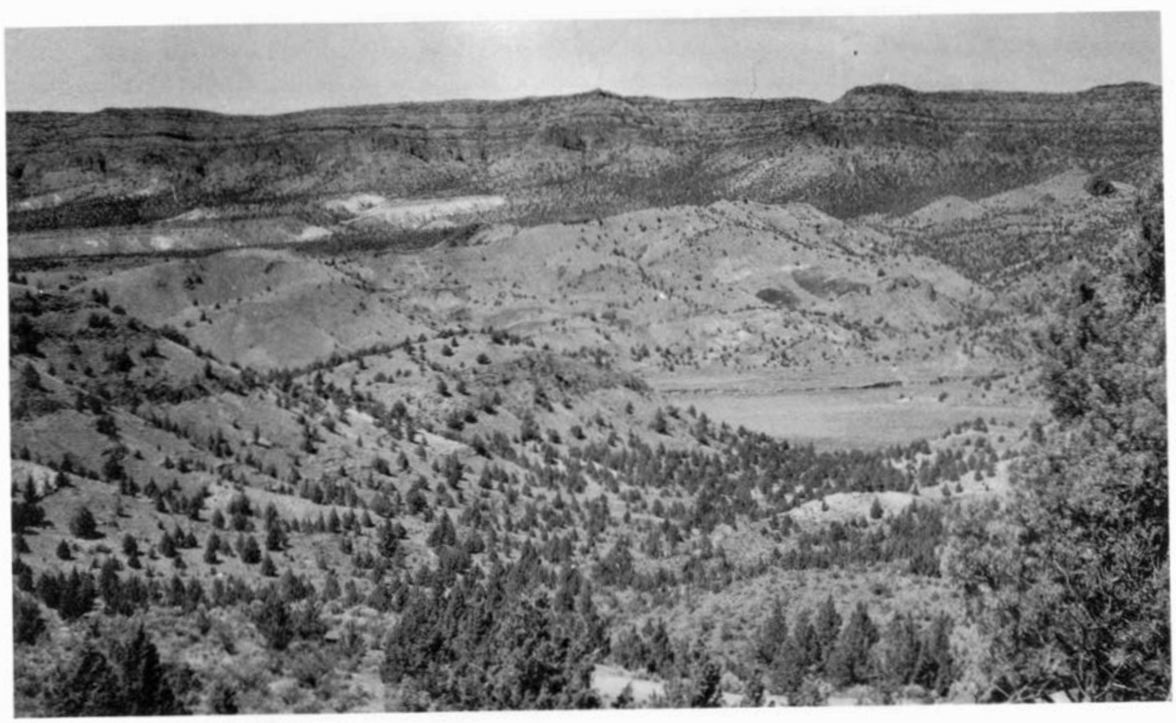


Figure 3. View north across Meyers Canyon to Sutton Mountain, composed of Tertiary rocks. Cretaceous rocks make up slopes in foreground.

Sedimentary structures

The primary sedimentary structures of these rocks are most obvious and varied within the conglomerates and sandstones of the Gable Creek Formation. However, certain sedimentary structures of environmental significance are present within the thin, generally discontinuous sandstones intercalated in the Hudspeth Formation (Figure 7). The structures described here, following the format of Potter (1963, p. 27), are divided into three types: unidirectional, those that indicate a one-way direction of transport; two-directional, those that indicate solely the line of transport; and non-directional. Table 3 lists the primary sedimentary structures which are sufficiently prevalent to warrant description.

Table 3. Classification of sedimentary structures in Gable Creek and Hudspeth Formations

Unidirectional	Two-directional	Non-directional
Cross bedding and cross lamination	Scour-and-fill	Graded bedding
Asymmetrical ripple marks	Symmetrical ripple marks	Plications and load casts
Imbricate structure	Planar structure	Mud cracks
Flute casts	Mudstone inclusions	Worm borings
	Parting lineation	

Scour-and-fill: Erosional channels, represented by scour-and-fill structures, are the most conspicuous and abundant primary sedimentary structures in the Gable Creek Formation. These two-directional structures also are common to lensing sandstone bodies intercalated in the mudstones of the Hudspeth Formation. Small-scale channels, a few inches wide and a few inches deep, generally are confined to the sandstones of the two formations. The largest channels, up to 300 feet wide and 30 feet deep, are restricted to the conglomerates of the Gable Creek Formation. The channels cut in cobble and boulder conglomerates (the results of traction transport at erosional interfaces) indicate that turbulence and velocity of the cutting currents were high. A similar conclusion might be true for the channels cut in mudstones, siltstones, or sandstones; however, an alternative could be that currents with less turbulence and velocity eroded the channels cut in finer textured materials.

The backfillings of the channels range from cobble and rare boulder conglomerates to very fine-grained sandstones. The latter are commonly confined to smaller channels cut in Hudspeth beds. The bedding of the infilled materials ranges from thick (5 feet) in conglomerates to laminae in very fine-grained sandstones. Channels filled with gravels generally have normal grading within the confines of the channel. The channels typically are lens-shaped, being fairly flat at the upper surface and rounded along the lower contact. The detrital backfilling commonly has foreset beds or laminae which are tangential below and truncated above by nearly horizontal overlying strata. Although the channels are two-directional structures, cross-bedded or -laminated backfilled strata aid in a unidirectional interpretation of the features. Directional measurements, combining channel elongation with inclination of foreset beds, demonstrate a predominate flow direction towards the south with a total range in direction from west-northwest to east-southeast.

Cross bedding and cross lamination: Cross-bedded or -laminated strata, mainly foresets, are second only to scour-and-fill structures in quantitative importance. The beds range widely in thickness from less than 0.5 inch (the cross-laminated) to more than 5 feet. The thickness of sets ranges from a few inches (notably in complexly cross-laminated sandstones) to more than 100 feet in a few of the conglomerates.

Commonly the basal contacts of foreset beds are erosional and concave downcurrent, the corresponding bedding being trough cross bedding (McKee and Weir, 1953, p. 385). Locally, however, many of the thicker foreset conglomerate beds have planar characteristics (Figure 5), and both planar and trough cross bedding can be found in the same outcrop.

Although cross bedding is common to the sandstones and is present here and there in the conglomerates, most conglomerate beds within the Gable Creek are laterally extensive and apparently were deposited in a nearly horizontal position. This suggests that many of the conglomerate sedimentation units are topset beds, and local red oxidized zones indicate that some may have been deposited and exposed subaerially.

Graded bedding: Graded bedding is common to most members of the Gable Creek Formation; it is inconspicuous in the sandstone intercalations of the Hudspeth Formation except where isolated lenses or channels contain coarse-grained pebbly sandstones as basal constituents. Both normal and reverse grading are prevalent in conglomerates, pebbly sandstones, and sandstones. Double grading, from finer at the base to coarser and then upward to finer at the top, is not uncommon. The graded bedding invariably is associated with other sedimentary structures, often scour-and-fill and foreset bedding. It is, therefore, interpreted as a product of fluctuations in current velocity and turbulence. It is of interest that in the modern alluviated valleys of this area recent deep dissection discloses fluvial sediments, ranging from gravels through sands to silts, which have normal, reverse, and, locally, double-graded bedding.

Ripple marks: Both symmetrical and asymmetrical ripple marks are present in the rocks of the area. The majority are found in the transition zones at the tops of Gable Creek tongues; however, short wavelength oscillation ripple marks do occur in some sandy zones of the Hudspeth Formation. The wavelengths of symmetrical ripples rarely exceed 1.5 inches and the amplitudes generally are less than 0.25 inches. At one locality, in rocks of Gable Creek tongue 6, asymmetrical ripple marks of cuspate shape have wavelengths of up to 8 inches.

The symmetrical ripple marks of very short wavelengths in the transition zones from conglomerates below to marine mudstones above, or within the sandstones of the Hudspeth Formation, are of significance mainly because of the associated features. In zones with ripple-marked strata there also are mudcracked layers, laminae with abundant plant debris, and local concentrations of pelecypods, gastropods, and worm tubes. This assemblage indicates deposition in shallow marine waters, probably within the tidal zones, and in an environment lacking strong wave or current action. Too few asymmetrical ripple marks were noted to substantiate directional interpretations.

Plications, load casts, and flute casts: The sandstone and siltstone units of the two formations contain zones of contorted bedding. In thin-bedded or laminated sequences there are internal convolutions or plications. These generally die out below in undisturbed strata, whereas above they commonly are truncated along nearly flat current-scoured interfaces. The plications represent distortions of hydroplastic beds under sedimentary loading. Because the folds either lack overturning, or do not show a preferred orientation of the inclined axes, an origin through subaqueous gliding or downslope movement cannot be established.

Basal structures in certain thin-bedded or laminated fine-grained sandstones units, notably the Hudspeth Formation, include load casts of varying types. These project as much as 8 inches downward into distorted laminae of mudstones or siltstones. Most of the load clasts have no directional properties and probably represent dislocations as the result of differential compaction under sedimentary load. However, at some localities, and generally where sandstones are intercalated in Hudspeth mudstones or siltstones, flute casts give directional indices which are consistent with interpretation of other sedimentary structures.

Mud cracks: Strata with small-scale mud cracks occur locally in transition zones between Gable Creek tongues and overlying Hudspeth rocks and also in some of the sandy zones within the Hudspeth tongues. The mud cracks generally are preserved at interfaces where flaggy, fine-grained sandstones are overlain sharply by mudstone or siltstone laminae. The small areas bounded by the mudcracks rarely exceed 0.75 inches in maximum dimension and generally are less than 0.5 inches. The crack-bounded

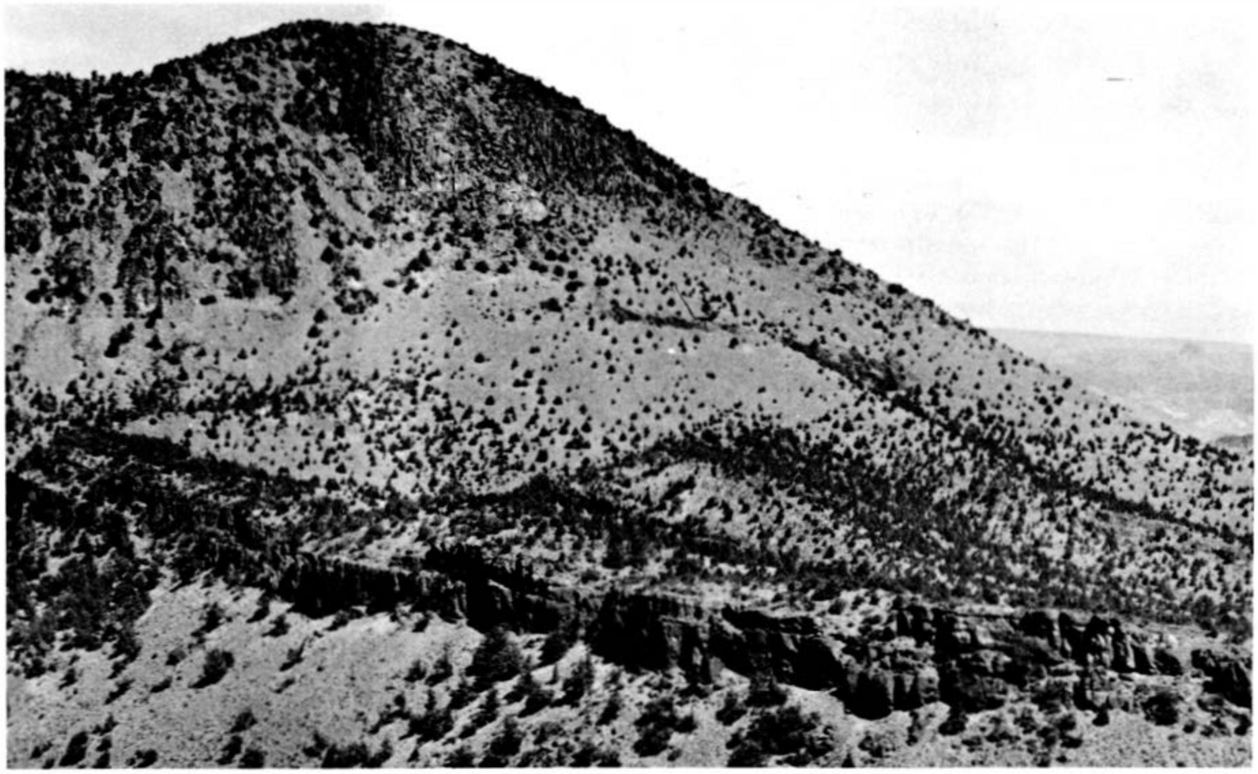


Figure 4. Gable Creek 3 cliff-forming units crop out on southeast flank of Black Butte, a Clarno sill.

Figure 5. Cliff-forming tongue of Gable Creek conglomerate and sandstone with large-scale planar foreset beds, southeast flank of Marshall Butte.

areas range in shape from triangles to polygons and are very irregular. Some of the bounding mudcracks are curved, others are straight. Ripple marks, woody debris, pelecypods, and worm tubes commonly occur within zones containing these subaerial structures.

Worm borings: Partly cylindrical and partly sinuous tubes ascribed to worm activity are locally abundant in some of the sandstones of the Hudspeth Formation. The sand-filled borings are generally less than 1 inch in length, and rarely as much as 3 inches. The tubes are confined to medium-or fine-grained sandstone layers in thin sheet sands, and they usually do not penetrate to the underlying siltstones or mudstones.

Mudstone inclusions: Some channel sandstones within the Gable Creek Formation contain widely scattered inclusions of laminated mudstone and rare laminated siltstone. The edges of these tabular to curved fragments generally are rounded. The inclusions range in size from minute blebs through discoidal pebbles up to slabs 4 feet long (Figure 6). Because the mudstone weathers more readily on outcrop than the enclosing sandstone, the positions of many former inclusions are marked by cavities. The inclusions are too isolated to permit designation of the rocks as intraformational conglomerates. However, as is true of many such conglomerates, the fragments appear to be "rip-ups" from previously deposited Hudspeth units. They are considered here as a two-directional phenomenon because the tabular fragments were deposited with the laminae parallel to the enclosing bedding and the long axes were aligned parallel to the current flow.

Imbricate and planar structures: Imbricate structure, a unidirectional feature, is sparse within conglomerates of the Gable Creek Formation. The structure is obvious and measurable only where the inclined pebbles are visible in a line of sight parallel to the depositional strike. Where imbrication is conspicuous the orientations reinforce current-flow directions obtained from other sources.

Far more common in the conglomerate units than imbricate structure is a fair to good preferred orientation of tabular or elongate pebbles and cobbles such that the long axes are parallel to the bedding. This planar structure, noted in all of the conglomerate units, is a two-directional structure very useful in the determination of bedding as well as in defining a current-flow direction.

Parting lineation: Parting lineation, is found within many of the horizontally laminated sandstones of the Hudspeth Formation. Consisting of shallow sub-parallel grooves and ridges of extremely low relief, this phenomenon is interpreted as a two-directional feature resulting from current flow. This interpretation is based upon the fact that adjacent foreset laminae or asymmetrical ripple marks invariably have strikes at right angles to the parting lineation. In all cases where parting lineation was noted, the measurements reinforced current-flow determinations obtained from other structures.

Interpretation of the rocks

Paleoslope: Mapping of directional structures in the two formations demonstrates that the varied structures mutually support a southerly current direction. Strikes of channel axes and asymmetrical ripples, inclinations of foreset strata, local imbricate structures in conglomerates, and parting lineation indicate that the paleoslope was to the south. Although individual current flow directions range from west-northwest through south to east-southeast, the vast majority define a transport direction which lay within the quadrant southwest to southeast. Significantly, the directional features and their interpretation in terms of paleoslope are supported fully by the geometry of the individual Gable Creek tongues--these wedge out, or thin, and become finer grained to the south. Moreover, Gable Creek tongues 1 and 2 each have terminations on both flanks of the Mitchell anticline, and lines across the axis which connect the termini of a single tongue give a crude depositional strike. For tongue 1 this is a N. 80° E.; for tongue 2 (removing the effects of strike-slip movement along the Mitchell fault) it is N. 70° E. These quasi-accurate results support a south or south-southeast declining paleoslope.

Figure 6. Conglomerates in scour-and-fill contact with sandstones. Note large Hudspeth Mudstone "rip-up" parallel to bedding at hammer handle. Goble Creek tongue 9, Bridge Creek road.

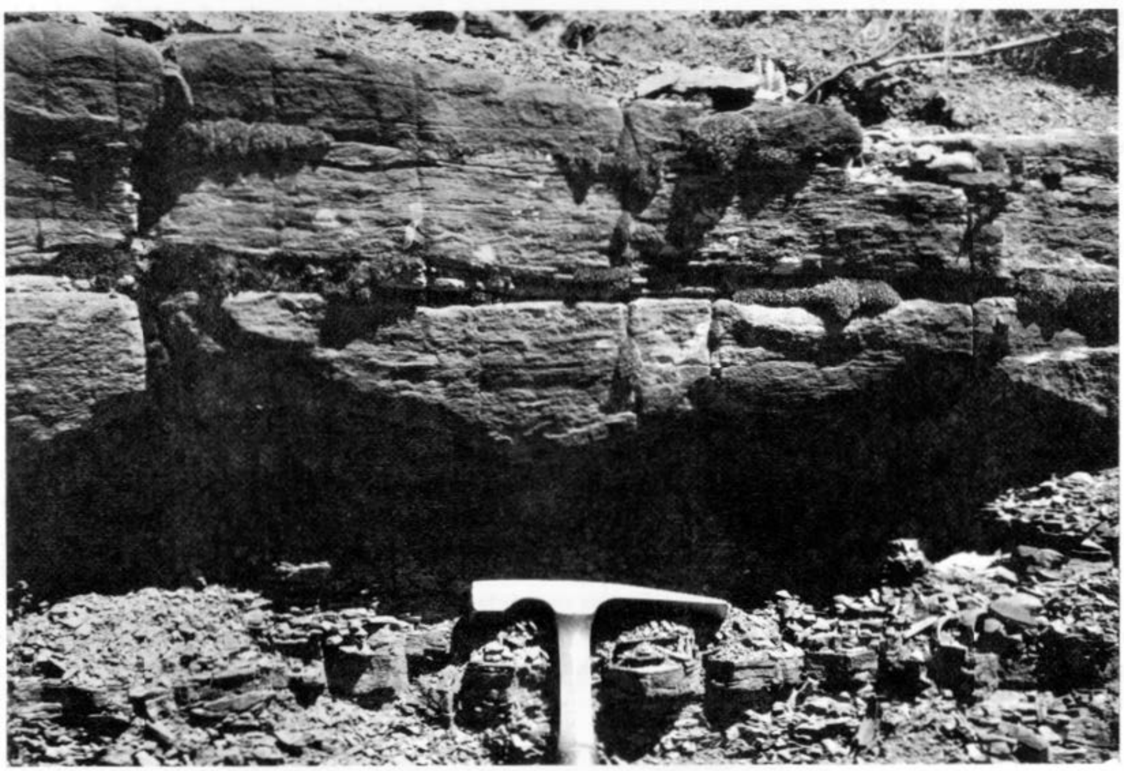


Figure 7. Laminated and cross-laminated, fine-grained sandstones in contact with laminated mudstones of Hudspeth tongue 6, upper Gable Creek.

Fluvial and deltaic processes: Most of the primary sedimentary structures are within the Gable Creek Formation. Principally the results of traction transport of gravels and sands by unidirectional currents, they were produced under differing conditions of velocity, turbulence, and load. Thicker cross-bed sets and larger channels are associated with conglomerates and coarse-grained sandstones. Moreover, the currents were strongest on the north where the conglomerates are coarsest and thickest and the channels widest and deepest. The currents were progressively weaker southward where the conglomerates wedge out or thin and grade transitionally into sandstones. Smaller channels in both formations contain laminated or thin-bedded trough cross-beds which are indicative of episodes of weaker unidirectional currents. If directional structures discussed above are linked with the shapes of tongues, the conclusion is reached that only fluvial processes, including those specifically ascribed to delta or fan building, could have caused the deposition of the great thicknesses of the Gable Creek Formation.

Basin of deposition: During Albian and Cenomanian times the sea encroached upon the eroded Permian metasediments, and transgressive marine sandstones and conglomerates were deposited. Following this transgression and the deposition of the Basal Member of the Hudspeth Formation, muds and silts of the Main Mudstone Member were deposited. Although this very thick member is persistent throughout the outcrop area, it tapers markedly to the north and east. Overlying these marine sediments is Gable Creek tongue 1, a fluvial-deltaic unit. In succession thereafter, dependent upon position within the quadrangles, Hudspeth and Gable Creek tongues succeed each other.

Multiple members of two formations, signaling juxtaposition of the marine and fluvial domains, pose questions regarding the conditions which permitted such intertonguing of widely differing lithic types. The Hudspeth mudstones and siltstones were deposited in quiet waters, below wave base; the Gable Creek tongues, prograding into the subsiding marine basin, are largely fluvial in origin. Each Gable Creek tongue, be it delta or fan deposit, is representative of strong currents which moved heavy loads of coarse detritus into the basin. Each Gable Creek tongue is transitionally overlain by a marine tongue of the Hudspeth Formation, representative of a renewed transgression by the sea.

The intertonguing depicts a series of episodic or possibly cyclic changes between marine sedimentation and continental deposition. The rock sequence could be simply the result of episodic subsidence of the basin, a subsidence noteworthy in that it was of such magnitude that it accommodated more than 9,000 feet of mixed sediments. On the other hand, the huge volumes of coarsely clastic Gable Creek debris may indicate strongly rising and strongly eroded source areas with an adjacent basin that was undergoing uniform subsidence. Thus, the Gable Creek tongues might represent the results of periodic strong uplifts of the source areas. A third possibility can be proposed--given a strongly rising source area subject to active fluvial processes, each conglomerate and sandstone tongue might represent a standstill in basin subsidence. During each standstill, under conditions of stable sea level, a regression of the sea caused by progradation of delta or fan fronts could be recorded by a protruding, more coarsely clastic tongue.

There really is no basis here in this limited area for selection of one of these mechanisms as the actual cause of the intertonguing. Consequently, there is a fourth possibility--that episodic subsidence of the basin, and periodic uplift of the source areas, employing swinging distributaries at the mouths of great rivers or protruding piedmont fans, combined to produce the complex intertonguing of widely differing rocks.

The marine basin was a strange one. The terminations of the conglomerate and sandstone tongues show no winnowing by wave action, no wave-cut features, and no longitudinal sand bodies oriented perpendicular to the regional slope which would be indices of active longshore currents. The absence of these, coupled with the prevalent lamination of the Hudspeth mudstones and siltstones and a very limited fauna, suggests that the basin was isolated and that it was restricted in wave action, current action, and benthonic activity. The basin was protected from the normal marine processes so prominent in open coastal areas. Thus emerges a picture of a large, sheltered, often shallow, marine embayment into which major rivers poured huge volumes of clastic debris.

CLARNO GROUP

Harold E. Enlows and Keith F. Oles

Introduction

The Clarno Formation was named by Merriam (1901) for rocks in the vicinity of Clarno Ferry on the John Day River. The Clarno is widely distributed throughout central Oregon with perhaps the thickest section reported by Waters and others (1951), 5, 800 feet of strata in the Horse Heaven district south of Clarno with neither base nor top exposed. Merriam states that, "The relations of the Clarno to the Cretaceous may be seen just east of the town of Mitchell." The relations of the Clarno to the overlying John Day can also be seen in the Mitchell area, and the stratigraphy, petrology, and age of the Clarno in the Mitchell area have been discussed by Oles and Enlows (1971) and Enlows and Parker (1972).

Age

Fossil vertebrates and leaves have been found in Clarno sediments which indicate an age of late Eocene. Enlows and Parker (1972) give K-Ar dates suggesting that the Clarno of the Mitchell area accumulated in the 16 million year span from 46 to 30 million years before present, or during late Eocene and early Oligocene (Table 4).

Stratigraphy in the Mitchell Area

The Clarno of the Mitchell area has been subdivided informally into Lower Clarno and Upper Clarno because two sequences of similar flows and volcanic-derived sediments are separated by an angular unconformity (see Table 1). All Clarno flows, however, are andesites so similar in lithology, petrology and chemistry that there can be no doubt concerning their comagmatic nature.

Lower Clarno rocks, reaching a thickness of 4,000 feet, consist chiefly of andesite flows intercalated with tuffaceous sandstones, siltstones, and minor conglomerates or breccias. The tuffaceous sediments superficially resemble those of the younger John Day Formation, but in the Mitchell area they can be differentiated because they are thinner, are intercalated between Lower Clarno flows, and are generally steeply dipping, having participated with the Lower Clarno flows in the orogenic episode that folded the Cretaceous rocks.

Upper Clarno rocks are found associated with Keyes Mountain, an exhumed early Oligocene volcano. Structural attitudes, thicknesses, and directional properties indicate that Keyes Mountain is the source of the Upper Clarno sequence in the Mitchell area. A series of lava flows and mudflows spread outward from the mountain, piling up strata to a thickness of at least 2,000 feet.

Perhaps the most interesting rock type of the Upper Clarno, a type found throughout Oregon where-ever Clarno is exposed, is the volcanic breccia or conglomerate which apparently was deposited as the result of mudflows or lahars (Figure 8). Uninterrupted sequences of mudflow deposits up to 1,000 feet thick have been found in the Mitchell area. Bedding and sorting are variable within the mudflows, and exposures range from massive deposits with barely discernible stratification and with boulders of huge size set in a matrix of all grade sizes including clay to far better sorted and bedded deposits. With increasing distance from Keyes Mountain the mudflow deposits grade toward more conventional fluvial deposits with a decrease in clast size and improvement in both bedding and sorting. The framework of these volcanic sediments

Table 4. Geochronology of the Clarno rocks of the Mitchell quadrangle (Enlows and Parker, 1972)

Epoch	Time in millions of years before present	Clarno rocks	John Day rocks near Mitchell	Age	North American land mammal stages
MIOCENE (lower)	-20-				
	-25-		Upper tuff	24.9my*	Arikareean
			Mid. ignimbrite	25.3my*	-- 25.6 --
OLIGOCENE					Whitneyan
					-- 29 ? --
	-30- UPPER CLARNO; Indicated span of Clarno igneous activity in the Mitchell Quadrangle	Nelson Creek dikes		29.4my	Orellan
			Lower John Day tuff	31.1my*	-- 31.6 --
	Orogeny***	Keyes Mtn. flows		32.7my	
		Airport dikes		33.3my	Chadronian
	-35-				-- ? --
		Lower Clarno bentonite**		36.5my*	
		Uppermost Lower Clarno flow		37.5my*	
EOCENE	LOWER CLARNO				Duchesnean
	-40-	White Butte (whole rock)		40.5my	-- 40 --
					Uintan
		Lowermost Lower Clarno flow		43.3my	
	-45-	Marshall Butte		44.8my	-- 45.4 --
		White Butte (hornblende)		46.1my	
	-50-				
	-55-				

Time scale after Harland, W. B., et al., 1964

* From Evernden, et al., 1964
** Stratigraphically below uppermost Lower Clarno flow
*** Orogeny occurred sometime between 37.5 and 32.7 million years ago
=== Precise boundaries between Epochs unknown

Figure 8. Clorna mudflow breccia near Clarno Bridge.

consists chiefly of fragments of Clarno andesite, but boulders of Cretaceous conglomerate, phyllite, silicified limestone, chert, and even quartzite are found in certain areas. Sand-sized clasts consist chiefly of fine-grained andesite, plagioclase, augite, hypersthene, hornblende and very subordinate quartz. The matrix consists of silt-sized grains of the above compositions with finer kaolinite, green smectite, and red to brown iron oxide. The only cement is green authigenic smectite which fills interstices and coats grains.

The stratigraphic succession of the Upper Clarno andesite flows and mudflow deposits is not simple. Lava flows and mud flows may be intercalated or intracanyon. The construction of Keyes Mountain was episodic; long intervals of weathering and erosion were separated by volcanic events. During periods of erosion valleys were carved by running water which became channels for later mudflows and lava flows.

All Clarno lava flows are andesites. They are predominantly porphyritic with a pilotaxitic groundmass, hornblende and hypersthene are common, and nearly all contain a trace of quartz. Phenocryst feldspar is generally labradorite; groundmass feldspar is andesine. An average mode is shown in Table 5.

Chemical analyses were made of seven flow rocks, three Upper Clarno and four Lower Clarno. Averages of these analyses with the average normative analyses derived from them are given in Table 6 and also in Table 7, next report.

Intrusives

Several conical topographic highs in the Mitchell quadrangle represent plugs of resistant igneous rock, and many less prominent hills and ridges have cores identified as dikes, sills, and irregular intrusions. Some of these intrusions are certainly of Clarno age (see Table 4), and most of the others are probably Clarno. Listed below are some of the major representatives of these intrusions.

White Butte andesite: In the core of White Butte is a typical Clarno andesite whose age has been determined by whole rock analysis as 40.5 million years and by its hornblende as 46.1 million years.

Table 5. Average modal analyses from eight Lower Clarno flows and 21 Upper Clarno flows

Mineral	Lower Clarno Flows	Upper Clarno Flows
Plagioclase	74%	80%
Augite	20	12
Magnetite	4	6
Hypersthene	1	2
Quartz	1	Tr
Hornblende	Tr	Tr
Glass	Tr	Tr

Table 6. Chemical analyses and derived normative compositions for Clarno flows.

Component			Upper Clarno (3 analyses)		Lower Clarno (4 analyses)		Average Clarno (7 analyses)
SiO_2			58.03		57.25		57.57
TiO_2			1.17		1.31		1.23
Al_2O_3			17.37		18.10		17.79
Fe_2O_3			1.64		1.75		1.70
FeO			4.89		5.26		5.10
MgO			3.57		3.33		3.43
CaO			6.97		7.33		7.17
Na_2O			4.92		4.38		4.61
K_2O			1.09		1.22		1.16
			Normative Composition				
Qz			5.16		5.34		5.82
Or			6.67		7.23		6.67
Ab			41.40		37.20		38.78
An			21.96		28.08		24.47
Di	Wo	10.2	5.22	6.83	3.48	8.99	4.64
	En		3.00		1.90		2.90
	Fs		1.98		1.45		1.45
Hy	En	9.6	5.90	11.02	6.40	8.34	5.70
	Fs		3.70		4.62		2.64
Mt			2.32		2.55		2.55
Il			1.28		2.43		2.28

Marshall Butte melabasalt: The large intrusive mass forming Marshall Butte, as well as several smaller outcrops extending to the west for six miles, consists of a rock composed of 70 percent augite with olivine, labradorite, and magnetite in about equal proportions forming the remaining 30 percent. The age of this rock is 44.8 million years.

Sargent Butte leucorhyolite: Sargent Butte and the adjoining Sand Mountain are composed of a distinctive pale orange, very fine-grained silicic rock classified as leucorhyolite and consisting largely of quartz and alkali feldspar.

Tony Butte dacite: A dacite plug penetrating both the Permian metasediments and the Cretaceous rocks forms the prominent topographic feature termed Tony Butte.

Andesite dikes, sills and irregular intrusions: Small widespread intrusions of typical Clarno andesite are common, especially in the crestal area of the Mitchell anticline.

Basalt dikes: A few basalt dikes composed of labradorite (An_{60}), and pigeonite with minor olivine and exhibiting a diabasic texture are found. (Airport and Nelson Creek dikes of Table 4.)

JOHN DAY FORMATION

Paul T. Robinson

Introduction

The John Day Formation in north-central Oregon is a conformable sequence up to 4,000 feet thick of tuffaceous claystones, vitric tuffs, lapilli tuffs, ash flow tuffs, and lava flows. It rests unconformably on the Clarno Formation, a thick unit of andesitic lava flows and volcanic breccias, and is overlain by the Columbia River Basalt. Based on paleontologic and radiometric ages the beds range from early Oligocene to early Miocene in age.

The formation was named by Marsh (1875) and Merriam (1901) from exposures along the John Day River between Clarno Ferry and Picture Gorge. No specific type section was designated; however, the Bridge Creek section in the Painted Hills northwest of Mitchell is typical of the formation as originally described. Here the formation consists of nearly 3,000 feet of varicolored rhyolitic, dacitic, and andesitic tuff and tuffaceous claystone with a few thin basalt flows in the lower part. It has been divided into three members on the basis of a widespread ash-flow tuff near the middle of the unit (Hay, 1963).

Stratigraphy: Bridge Creek Section

Lower member

The lower member is approximately 1,100 feet thick and consists chiefly of red, green, and gray-green tuffaceous claystones and interbedded vitric tuffs. The red claystones form a distinctive basal layer generally 50 to 100 feet thick but up to 450 feet thick in some localities (Hay, 1963). The vitric tuffs are medium to coarse grained with a few pumice lapilli and 5 to 10 percent of crystals and rock fragments. The crystals are mostly plagioclase (oligoclase and sodic andesine) and sanidine with small amounts of green pyroxene; quartz is rare or absent.

Two tuff beds in the lower member are of particular interest. The first is a 25- to 50-foot-thick ash-flow tuff that occurs at the base of the formation along Rowe Creek northwest of Twickenham. This tuff is cream colored, moderately welded, and has a weakly developed eutaxitic texture. It contains sparse rock fragments and 5 to 10 percent of sanidine, quartz, and oligoclase crystals suggesting a rhyolitic composition. Based on its stratigraphic position and mineralogic composition this tuff has been tentatively correlated with the welded tuff that forms the base of the formation near Clarno, 15 miles to the northwest (Hay, 1963: Swanson and Robinson, 1968). The second tuff is a coarse-grained, sanidine-rich, air-fall unit that lies 500 to 800 feet above the base of the formation. This tuff is usually 1 to 3 feet thick but may be as much as 30 feet thick where it has been reworked (Hay, 1963). The sanidine occurs in euhedral crystals, 1 to 4 mm long, often mantled with myrmekitic intergrowths of quartz and having a composition of $Or_{43}Ab_{54}An_{3}$ (Hay, 1963). This bed is considered the air fall equivalent of a sanidine-rich ash-flow tuff exposed in the Antelope-Ashwood area 25 miles to the northwest (Hay, 1963; Robinson, 1966).

Middle member

The middle member of the formation is a rhyolitic ash-flow tuff sequence 12 to 250 feet thick composed of two partial cooling units. Glass shards and fragments make up approximately 97 percent of the tuff with the remainder consisting of oligoclase and sanidine crystals and sparse rock fragments. Where welded and devitrified the tuff forms a prominent ledge that can be easily traced in the field. The lower cooling unit is the most extensive of the two and has been recognized over a wide area (Fisher, 1966).

Upper member

The upper member is 1,300 to 1,700 feet thick and consists of claystones and tuffs with some conglomerate and sandstone near the top. The claystones and tuffs are similar to those of the lower member except for the color, which is chiefly yellowish-gray to light olive-gray (Hay, 1963). Crystals and rock fragments make up to 10 percent of typical specimens; the remainder consists of fresh or altered glass. Andesine is the principal crystal with sanidine and quartz being rare to absent. Ferromagnesian minerals include clinopyroxene, magnetite, ilmenite and small quantities of hornblende and biotite. The conglomerates and sandstones are abundant only in the upper 500 feet of the unit. They consist chiefly of materials reworked from the upper member but include some pebbles and cobbles of welded tuff and andesite (Hay,1963).

Stratigraphy: Clarno-Antelope-Ashwood Area

West of the lower John Day River, in the Clarno-Antelope-Ashwood area, the stratigraphy of the John Day Formation is markedly different from that in the type locality. Here the formation has an aggregate thickness of nearly 4,000 feet and contains abundant lapilli tuff, welded ash-flow tuff, and lava flows and domes (Waters, 1954; Peck, 1964). It has been divided into 9 members, A through I, primarily on the basis of extensive ash-flow tuffs (Peck, 1964).

Member A

The basal unit of the formation, member A, consists of two ash-flow tuffs separated by about 100 feet of white lapilli tuff. The lower ash-flow tuff is the most extensive of the two and can be traced nearly continuously from Pine Creek near Fossil to Grizzly, a distance of approximately 45 miles (Swanson and Robinson, 1968). It is typically strongly welded, with a well developed eutaxitic texture, and contains 5 to 10 percent of crystals, chiefly quartz, sanidine and oligoclase, with trace amounts of green hornblende. Potassium-argon dates of 36.1 and 36.4 m.y. have been obtained from this tuff, suggesting an early Oligocene age.

Members B-G

Overlying member A are a series of trachyandesite and rhyolite flows, members B and C respectively, which in turn are overlain by a thin unit of poorly indurated, light-gray to yellow tuff and lapilli tuff (member D), and a thick sequence of extremely lithophysal welded tuff (member E). Member F is composed chiefly of poorly indurated, gray to brownish-gray tuff and lapilli tuff with a sequence of alkali-olivine basalt flows in the upper part (Robinson, 1969) (Table 7). Member G consists of a basal ledge-forming ash-flow tuff, 20 to 100 feet thick, overlain by 100 to 400 feet of gray and brownish-gray tuff and lapilli tuff. The basal ash-flow tuff contains 10 to 15 percent of euhedral sanidine phenocrysts from 1 to 5 mm long. The sanidine crystals have an average composition of $Or_{43}AbAn_{57}$ and are mantled with myrmekitic intergrowths of quartz and sanidine (Peck, 1964). These crystals are very similar in composition and character to those of the sanidine-rich air-fall tuff in the Painted Hills section.

Table 7. Average chemical analyses of selected Tertiary volcanic rocks of north-central Oregon (Recalculated to water-free basis)

	1	2	3	4	5
SiO_2	47.1	50.2	54.6	57.57	50.3
TiO_2	3.6	1.6	2.0	1.23	1.47
Al_2O_3	15.4	15.7	14.1	17.79	16.2
Fe_2O_3	6.6	3.6	2.6	1.70	-
FeO	8.8	7.9	9.4	5.10	10.3*
MnO	0.2	0.2	0.2	-	-
MgO	5.0	6.6	4.2	3.43	7.8
CaO	8.6	10.5	8.0	7.17	10.4
Na_2O	3.2	2.7	3.0	4.61	3.1
K_2O	0.9	0.5	1.5	1.16	0.32
P_2O_5	0.6	0.3	0.4	-	-
No. Analyses	13	16	8	7	11

1. Alkali olivine basalt, John Day Formation (Robinson, 1969).
2. Picture Gorge type, Columbia River Basalt (Waters, 1961).
3. Yakima type, Columbia River Basalt (Waters, 1961).
4. Clarno andesite (Oles and Enlows, 1972).
5. Basalt, Deschutes Formation (Taylor, unpub. anal., 1972).

*Total Iron

Member H

The base of member H is also marked by a ledge-forming ash-flow tuff. This tuff is red, reddish-brown or orange in color, fine-grained and sparsely lithophysal. Trace amounts of quartz and oligoclase are present in most specimens. About 300 feet of poorly indurated, light-gray tuff and pumice lapilli tuff overlie the basal tuff.

Member I

The uppermost member, member I, consists of 600 to 800 feet of massive light-gray to yellowish-gray tuff and pumice lapilli tuff overlying another ash-flow sheet. The basal ash-flow tuff is moderately to weakly welded, rarely devitrified, and characterized by large collapsed pumice fragments and chips of black glass. It contains sparse crystals, chiefly oligoclase, and 1 to 2 percent of rock fragments.

Correlations

Correlation of the western and eastern facies of the John Day Formation is based on the basal tuffs of members A and G. The basal tuff of member A can be traced eastward from the Ashwood area to the crest of the Blue Mountain uplift, and is believed to correlate with the basal ash-flow tuff along Rowe Creek to the east (Swanson and Robinson, 1968). The basal ash-flow sheet of member G is believed to correlate with the sanidine-rich air-fall tuff in the Painted Hills area. This correlation is based on the similarity in size, shape, and composition of the sanidine crystals in the two units and is strongly supported by the changes that occur in the ash-flow tuff of member G as it is traced from west to east. In its westernmost exposures this tuff is up to 100 feet thick and is densely welded. It thins gradually to the east and northeast, and in the vicinity of Willowdale it grades into an unwelded ash-flow tuff. Farther east, in the area between Antelope and Clarno, it grades into a crystal-rich air-fall tuff like the one exposed near the Painted Hills, about 13 miles to the east.

If these correlations are correct most of the section in the Clarno-Antelope-Ashwood area is equivalent to the lower 500 to 800 feet of the formation in the Painted Hills area. Uplift along the Blue Mountain anticlinorium apparently began in early John Day time, soon after the eruption of the ash-flow tuffs of member A. Uplift along this axis resulted in a topographic barrier that prevented most of the ash flow sheets and lava flows of the western facies from reaching the Painted Hills area.

COLUMBIA RIVER BASALT

Paul T. Robinson

The Columbia River Basalt is middle Miocene in age and unconformably overlies the John Day Formation in north-central Oregon. Waters (1961) divided the Columbia River Basalt into the Picture Gorge, Yakima, and late Yakima varieties based on mineralogical and chemical composition (Table 7). Only the Picture Gorge and Yakima types are recognized in north-central Oregon. The Picture Gorge Basalt, the oldest of the two, crops out chiefly along the southern flank of the Blue Mountains and in the Ochoco Mountains (Swanson, 1969). It consists of a series of columnar-jointed flows, generally 50 to 100 feet thick, locally separated by lenticular interbeds of tuff and tuffaceous siltstone. Directional features suggest that most flows were erupted from vents or fissures to the east or northeast, in the vicinity of the Monument Dike Swarm (Thayer, 1957; Waters, 1961).

The basal parts of most flows weather to a characteristic basaltic grus with a greasy luster. Picture Gorge basalts are typically fine- to medium-grained with intergranular to ophitic textures and are commonly porphyritic. Some parts of flows are very coarse-grained grading into pegmatitic zones. A typical mode is 8 percent glass, 40 percent plagioclase, 35 percent clinopyroxene, 5 percent olivine, 5 percent iron oxides, and 7 percent clay minerals (Swanson, 1969).

The Yakima Basalt crops out chiefly on the northwest side of the Blue Mountains, except in the Spray area where it unconformably overlies the Picture Gorge Basalt (Lindsley, 1960). The Yakima Basalt is composed of dark gray, dense, columnar-jointed flows that weather into subangular, fist-size fragments.

The flows are fine- to very fine-grained, rarely porphyritic, and non-vesicular, except in the upper few feet. Typical specimens consist of 25 percent glass, 30 percent plagioclase, 25 percent clinopyroxene, 10 percent iron oxides, and 10 percent mineraloids, clay minerals, and olivine. Olivine is sparse in most flows and is typically in reaction relation to clinopyroxene.

Both the Picture Gorge and Yakima Basalts are tholeiitic in character, distinctly different from the alkali olivine basalts of the John Day Formation (Table 7).

MASCALL FORMATION

Harold E. Enlows

Introduction

Merriam (1901) applied the name "Mascall" to a series of air-fall tuffs and both fluviatile and lacustrine volcanic sandstones and siltstones exposed at and near the Mascall Ranch four miles west of Dayville, Oregon (Figure 9). The fauna and flora collected by Merriam and associates, Chaney (1956) and Downs (1956) indicate a Hemingfordian (middle Miocene) and Barstovian (late Miocene) age. An unfortunate difference of opinion arose concerning the total thickness of the section in the type locality; Merriam and others (1925) measured 2,090 feet while Downs (1956) reported 390 feet. Thayer and Hay (1950) give an estimate of 2,000 feet which agrees with the author's investigations.

Evernden and others (1964) give a K-Ar date of 15.4 million years to the Columbia River Basalt flow directly underlying the Mascall in a roadcut on U.S. 26, 13 miles east of Dayville. Davenport (1971) assigns an age of 15.8 million years to an ignimbrite interbedded with basal Mascall sediments collected from an exposure near the confluence of Deer Creek and the South Fork of the John Day River about 20 miles south of Dayville.

Stratigraphy and Petrology

The Mascall is found to the north of the type section in Fox Valley, to the south in the Paulina Basin and headwaters of the Crooked River, and east as far as Prairie City in the John Day Valley. Thayer and Hay (1950), discussing the Mascall found in the John Day Volley and adjacent areas, state, "The later Miocene landscape in this region appears to hove been characterized by eruption centers around o broad basin. At the maximum of basaltic eruptions, extensive flows filled the basin to a depth of 1,500 feet or more. Increasing rhyolitic activity appears to hove coincided with enough of a decline in basaltic eruptions that basalt flows failed to reach the center of the basin, and the deposition of acidic fragmentals and their erosion derivatives continued until diastrophism destroyed the basin. As the basin deposits interfingered with the volcanic rocks, the Mascall Formation, in the broad view, should be regarded as a member of the Columbia River Formation (Group), rather than as a distinct and younger formation."

The Mascall rocks of the type locality bear a distinct resemblance to the John Day rocks. They are generally light colored, porous, poorly indurated and rich in acidic glass shards or phyllosilicates derived from acidic glass. They may exhibit air-fall characteristics, but more commonly the pyroclastic debris they contain seems to have been reworked by running water or sheet wash, and the rocks now give evidence of fluviatile or lacustrine environments. Textural varieties range from conglomerates to claystones, diatomite is common, lignite is not uncommon, both leaves and pelecypods are found in some zones, and in at least one instance an interbedded ignimbrite is present.

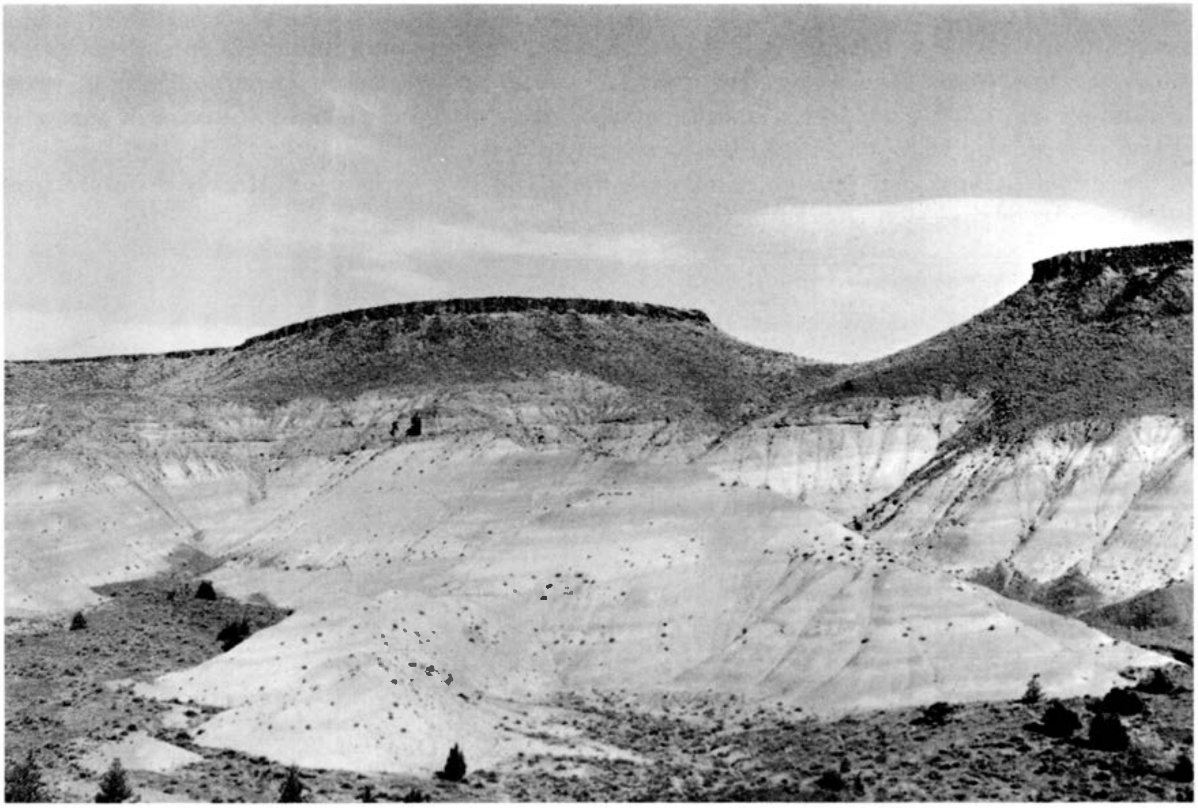


Figure 9. Lower Rattlesnake fanglomerate resting unconformably upon the Mascall Formation. Rattlesnake Ignimbrite on skyline. Rattlesnake Creek.

RATTLESNAKE FORMATION

Harold E. Enlows

Introduction

J.C. Merriam (1901) named the Rattlesnake Formation of the John Day Valley from an occurrence on Rattlesnake Creek, "about one mile west of Cottonwood." Later (1925) Merriam, Stock, and Moody stated that, "The area of Rattlesnake exposed in the butte west of Picture Gorge has generally been termed the type section, and although it really represents but a small part of the entire succession within the formation, it was subjected to more careful study than elsewhere, due to the presence of mammalian fossils in the tuff and in the gravel." Capping the section in the butte west of Picture Gorge is a rock unit they referred to as a rhyolite flow or the "Rattlesnake Rhyolite." They also state, "On Cottonwood Creek and in practically all Rattlesnake areas east of Picture Gorge, however, a very considerable thickness of gravels overlies the rhyolite."

Stratigraphy and Petrology

From two locations, one on Rattlesnake Creek and one on Cottonwood Creek, it has been possible to measure and describe a composite section now termed the type section. The Rattlesnake Formation has been subdivided into three members as listed in Table 8.

Table 8. Stratigraphic column of the Rattlesnake Formation in the type section

	Thickness	Field Description
Upper Fanglomerate Member	370'	Coarse fanglomerate of uniform composition and lithology throughout. Boulders 2-3 feet in diameter are encountered but more commonly the framework is composed of smaller boulders, cobbles and pebbles. Framework clasts are rounded to subangular and consist predominantly of Picture Gorge Basalt although firmly welded ignimbrite from the Rattlesnake Tongue is not uncommon. A crude bedding is defined by discontinuous lenses of coarse sandstone. Poorly cemented, commonly slope-forming.
Erosional; disconformity		
Rattlesnake Ignimbrite Tongue	41'	A single flow unit and a simple cooling unit, the result of an extensive nuée ardente type eruption. It is separated into three zones; a thin, light-gray, unwelded base, a brownish-gray moderately to firmly welded columnar middle zone, and a pale red poorly welded upper zone. The rock consists largely of pumice, glass shards, and accidental lithic fragments with only 1% cognate mineral grains. It is classified as leuco-sodaclase rhyodacite.
Lower Fanglomerate Member	218'	Conglomerate with thick interbeds of yellowish-gray poorly bedded volcanic wacke and grayish-orange-pink poorly bedded volcanic mudstone in the ratio of 63% conglomerate, 21% wacke and 16% mudstone. These textured units are thick, discontinuous lenses laterally continuaus for short distances only.
Angular unconformity		
Mascall Formation		

The Rattlesnake Formation in the valley of the John Day River and its tributaries generally consists of two fanglomerate members separated by a thin, poorly zoned rhyodacite ignimbrite resulting from a single ash flow (Figure 10).

The fanglomerate members consist largely of conglomerates and sandstones composed of clasts derived from highlands adjacent to the river valleys. The clasts reflect the bedrock geology of those highlands and in the type area consist chiefly of mafic volcanics, minor smectite pseudomorphs after volcanic grains, feldspar and pyriboles. The only important cement is authigenic smectite coating grains and filling interstices. Based upon mammalian remains found by Merriam (1901) and Merriam and others (1925) the Wood Committee, (1941) placed the Rattlesnake in Hemphillian time. Additional finds by Davenport (1971) and Enlows are consistent with the earlier ones.

The ignimbrite (Figure 11) extends beyond the underlying fanglomerate member and commonly rests upon older bedrock at what must have been the edges of the ancestral stream valleys, hence it is referred to as the Rattlesnake Ignimbrite Tongue. It apparently originated from a vent in the Harney Basin and flowed north into the drainage systems of the ancestral John Day River, moving to the northwest for at least 140 miles. In the type area where it was described by Merriam it is at least 100 miles from its source. To the south it is referred to by the author and his students as "The Rattlesnake Ignimbrite Tongue of the Danforth Formation" since it is the uppermost of three ignimbrites found in the Danforth. It consists largely of glass shards, pumice fragments, and accidental inclusions picked up from the underlying terrain. Cognate minerals form only one percent of the rock and in order of abundance consist of anorthoclase ($Or_{30}Ab_{70}$), quartz, green clinopyroxene, magnetite, and zircon. In the John Day drainage it exhibits a thin basal and thicker top unwelded zones and a firmly welded central columnar zone.

Chemical analyses from widely separated samples of the ignimbrite in the John Day drainage are strikingly similar. The average chemical analysis and the normative analysis derived from it are given in Table 9. Since the rock consists of 99 percent glass it was thought useful to treat the norm as the mode and classify the rock according to the classification of Johannsen (1939). Such a procedure suggests the name leuco-sodaclase-rhyodocite.

A K-Ar date of 6.4 m.y. is confirmed by several analyses. The geomagnetic polarity is reversed.

Table 9. Average of four chemical analyses of the Rattlesnake Ignimbrite Tongue from the John Day drainage and the normative analysis derived from it

SiO_2	78.22	Qtz	40.08
TiO_2	.23	Or	24.47
Al_2O_3	12.41	Ab	31.44
Fe_2O_3	.57	An	.84
MgO	.24	Il	.45
CaO	.15	Mt	.64
Na_2O	3.74	En	.60
K_2O	4.18		98.52
P_2O_5	.01		
MnO	.19		
	99.94		

Total iron expressed as Fe_2O_3.

Analysis in dry wt. %.

Accidental lithics have been removed from all samples.

Figure 10. Rattlesnake Ignimbrite Tongue lying between the fanglomerate members, Cottonwood Creek.

Figure 11. Rattlesnake Ignimbrite with the basal light-gray unwelded to poorly welded zone, middle firmly welded columnar zone, and upper slabby poorly welded zone.

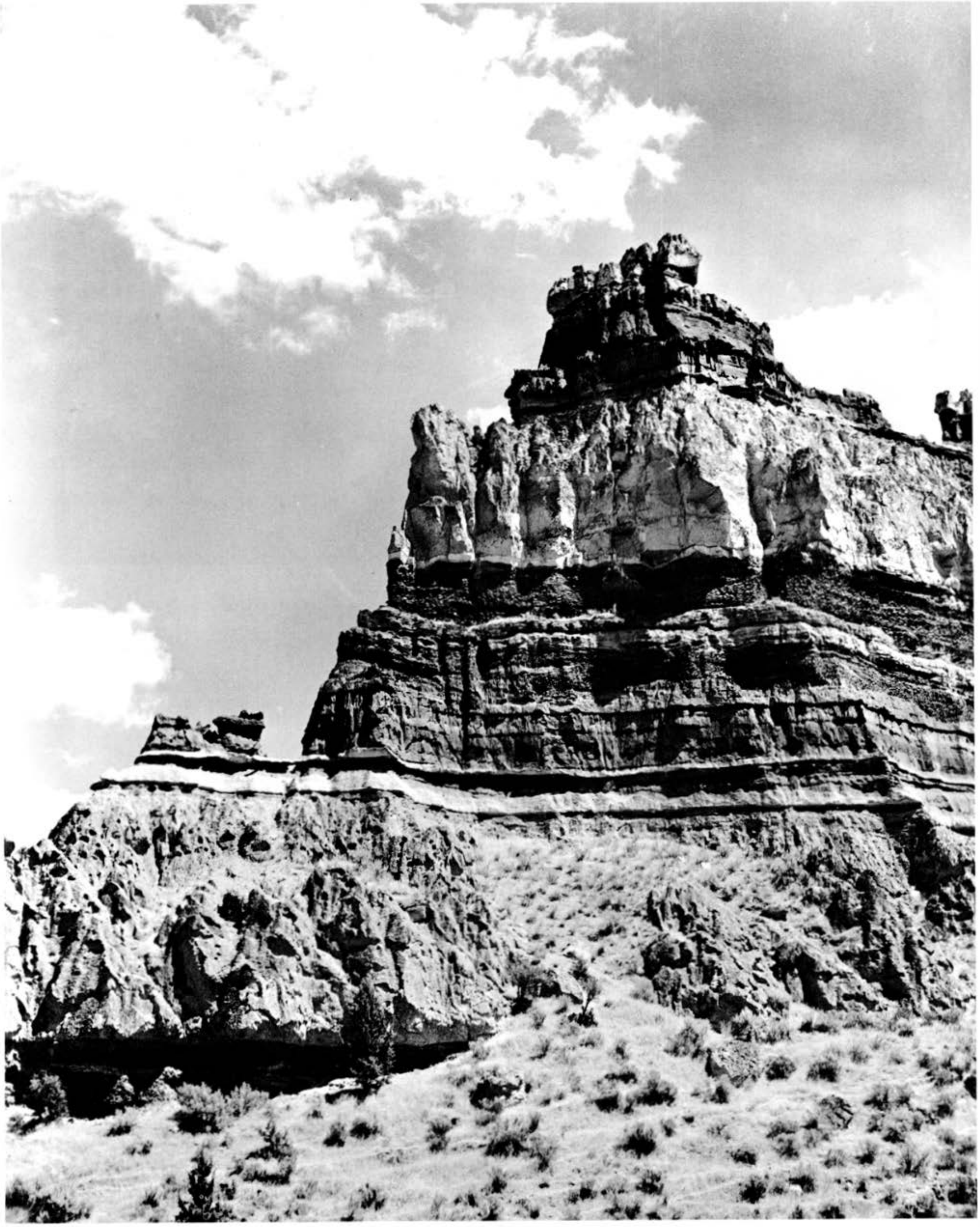


Figure 12. "The Ship" in The Cove Palisades State Park. Section of the Deschutes Formation showing interlayered ash-flow tuffs and sediments. State Highway Division photo

GEOLOGY OF THE DESCHUTES BASIN

Edward M. Taylor

Introduction

The Deschutes Basin is a broad lowland lying south of the Mutton Mountains and between the Ochoco-Blue Mountain uplift on the east and the Cascade Mountains on the west. The basin contains widespread sheets of basaltic lava and silicic ash-flow tuff interstratified with tuffaceous silts, sands, and gravels of the Pliocene Deschutes Formation. In general, basalt sheets are indigenous to the basin while ash-flow tuffs are of Cascade origin. Some of the coarse sediment was derived from older rocks to the east, and some might have been contributed by rivers draining the high lava plains to the south, but most of the sedimentary units are composed chiefly of alluvial debris from Cascade volcanoes. Where both top and bottom of the Deschutes Formation are exposed in the walls of lower Deschutes Canyon, the maximum thickness is approximately 250 meters. It is reasonable to assume that the thickness of the formation increases westward in the direction of the Cascade sources.

Some basalt sheets and ash-flow tuff units within the Deschutes Formation can be traced continuously for many kilometers in canyon walls of the Deschutes River and its tributaries (Figure 12). Regional inclination of these strata is east by northeast, away from the Cascade Mountains and toward the eastern margin of the basin. The angle of inclination seldom exceeds two degrees and probably represents the initial dip of the sedimentary units and the gradient of paleosurfaces upon which lavas and ash-flow tuffs were deposited. Folds and faults of tectonic derivation are virtually unknown. One of the most striking features of the Deschutes Basin is this almost total absence of deformation during a period of extensive normal faulting in adjacent areas to the east, south, and west.

Deschutes Formation

Lavas

Pliocene and younger lavas of the Deschutes Basin are chiefly of two types: (1) high-alumina, olivine-bearing basalt with a silica content generally ranging between 48 and 52 percent and a K_2O content which seldom exceeds 0.5 percent, and (2) high-alumina basaltic andesite with a silica content ranging from 52 to 58 percent while K_2O usually exceeds 0.5 percent. Basalts occur as widespread sheets and as intracanyon tongues; basaltic andesites are found in thick, stubby flows and in large shield volcanoes marginal to the Cascade Mountains. The basalt flows are usually diktytaxitic and highly vesicular. Spiracles, pipe vesicles, and vesicle cylinders are common, and horizontal jointing occurs parallel to vesicle sheets. Where it has cooled in intracanyon wedges, the basalt tends to be uniformly fine-grained, not vesicular, and possesses well-developed columnar joints. Flows of basaltic andesite are usually glomeroporphyritic and dense and display close-set platy joints along basal contacts.

Ash-flow tuffs

Ash-flow tuffs in the Deschutes Formation are composed of poorly-sorted pumice bombs, lapilli, and ash mixed with fragments of basalt and basaltic andesite. The silica content of the glassy pumice, together with entrained crystals, ranges from 68 to 74 percent. Many ash-flow units are more than 30 meters thick and contain only a thin, central, discontinuous welded zone. Other ash-flow units are less than 10 meters thick and are welded throughout, except for relatively thin, unconsolidated basal and crustal zones. A part of each ash-flow unit was subjected to extensive erosion prior to burial and preservation. When traced toward the Cascade Mountains, the number and thickness of ash flows, degree of welding, size of particles, and content of mafic lava fragments increase.

Beds of demonstrable ash-fall origin are rare in the Deschutes Formation. A few thin, graded beds of accretionary lapilli are known in the upper part of the formation but, in general, it appears that many of the ash-fall deposits that must have formed in the basin following Cascade eruptions were efficiently reworked into fluviatile and lacustrine sediments.

Sediments

Basalt and basaltic andesite sands and gravels, together with pumiceous lapilli and ash, are the most abundant constituents of Deschutes fluviatile sediments. Fragments of andesitic, dacitic, and rhyolitic flow rocks are relatively rare. Some poorly-sorted, coarse-grained units of apparent mudflow origin contain all of the rock types mentioned above. Strata that appear to have been deposited in bodies of standing water are composed of well-sorted sand grains or, more commonly, glass shards and diatoms in thinly laminated beds. However, Deschutes Formation sediments present all intermediate conditions of sorting and grain size between the extremes of mudflow and lake bed. Innumerable abrupt changes in stream and load characteristics are recorded on both large and fine scale throughout the formation. Cut-and-fill structure, cross-bedding, and beds deformed by subaqueous slumping occur so abundantly as to suggest a complex history of deposition and redeposition by shifting, unstable streams, intermittently swollen during times of heavy rainfall and seasonal discharge of meltwater from the mountains.

Modern streams are cutting into the soft tuffaceous sediments of the Deschutes Formation, undermining the more resistant basalt wherever it forms rimrocks, ledges, and waterfalls. Slumping from the canyon walls produces broad tongues and aprons of debris. However, it should not be assumed that sediments of the Deschutes Basin are being or have been rapidly stripped away. Several widespread units of rimrock basalt yield K-Ar ages close to 4.8 million years, and sediments from the upper part of the Deschutes Formation were assigned an age of 5.3 million years by Evernden and James (1964). With the exception of relatively small areas covered by younger lavas, most of the Deschutes Formation has been exposed to erosion for about 5 million years. In that time only a small part of the basin has been deeply dissected.

The concept that the Deschutes Formation sediments accumulated in a downwarped structural basin lacks supporting evidence. The formation was more likely deposited as an alluvial prism at the east base of a Pliocene Cascade Range because an episode of Cascade volcanism, terminating about 5 million years ago, supplied far more volcanic detritus to the ancestral Deschutes drainage system than could be carried away.

Intracanyon Basalts

The Metolius River rises in the Cascades directly to the west of the Deschutes Basin, and the Crooked River drains the Ochoco Mountains southeast of the basin. Both rivers join the Deschutes River in The Cove Palisades State Park. Each of these rivers has carved impressive, steep-sided canyons into the Deschutes Formation, and each of these canyons has been partially filled with flows of basalt, only to be vigorously re-excavated. Flows intracanyon to the Metolius were derived from a High Cascade vent, were relatively thin, and were superimposed above one another to form a composite valley fill. Flows intracanyon to the Crooked and Deschutes Rivers are narrow extensions of a vast flood of lava which poured out south of the basin and nearly obliterated the valleys beneath thick, V-shaped wedges of basalt. Deschutes Canyon was the first to receive a tongue of this basalt. After this first flow had been extensively removed by the Deschutes River, a second and larger surge of basalt entered Crooked River Canyon, filled it nearly rim to rim, poured 8 kilometers downstream from The Cove (a narrow peninsula separating the lower Crooked and Deschutes Rivers in The Cove Palisades State Park) and moved 5 kilometers upstream into the Deschutes Canyon. All of these intracanyon flows were probably formed during late Pleistocene and are now preserved as remnant benches along canyon walls.

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CRETACEOUS AND CENOZOIC STRATIGRAPHY OF NORTH-CENTRAL OREGON

ROAD LOG

FIRST DAY

Leave Portland 8:00 A.M., arrive The Cove Palisades State Park, STOP1-1, at 11:00 A.M., spend one hour examining Deschutes Formation and intracanyon basalt flow, then lunch at The Cove State Park. Return to Madras.

Turn-out stop: Highway grade above The Cove State Park. In the road cut are units of ash-flow tuff, cross-bedded sands and gravels, alluvial pumice, a possible lahar, and a flow of columnar-jointed basalt locally intracanyon to ancient channels in the Deschutes Formation. The view south includes the sharp contact between the Deschutes Formation and a remnant bench of younger intracanyon basalt.

Viewpoint stop: East rim of Crooked River Canyon above The Cove State Park.
View East: Ochoco foothills composed of Clarno, John Day and Columbia River Group rocks rising above the broad undissected surface of the Deschutes Basin.
View South: Two-step profile of Crooked River Canyon, partly filled by a thick intracanyon flow of Pleistocene basalt.
View West: Canyon of Crooked River. The Cove State Park facilities below are built on one of many landslide blocks that can be seen along the base of the cliffs. The elongate mass of columnar-jointed basalt standing above the far side of the reservoir is a remnant of Pleistocene intracanyon flow rock that now forms a narrow, flat-topped divide between the Crooked and Deschutes Rivers. Flat-lying strata in the canyon walls are composed of Pliocene sands, gravels, ash-flow tuffs and basalt flows (Figure 12). Foothills and peaks of the Cascades can be seen in the distance.
View North: The shield volcano surmounted by a cone of red cinders is called Round Butte and is one of the younger sources of local rimrock basalt.

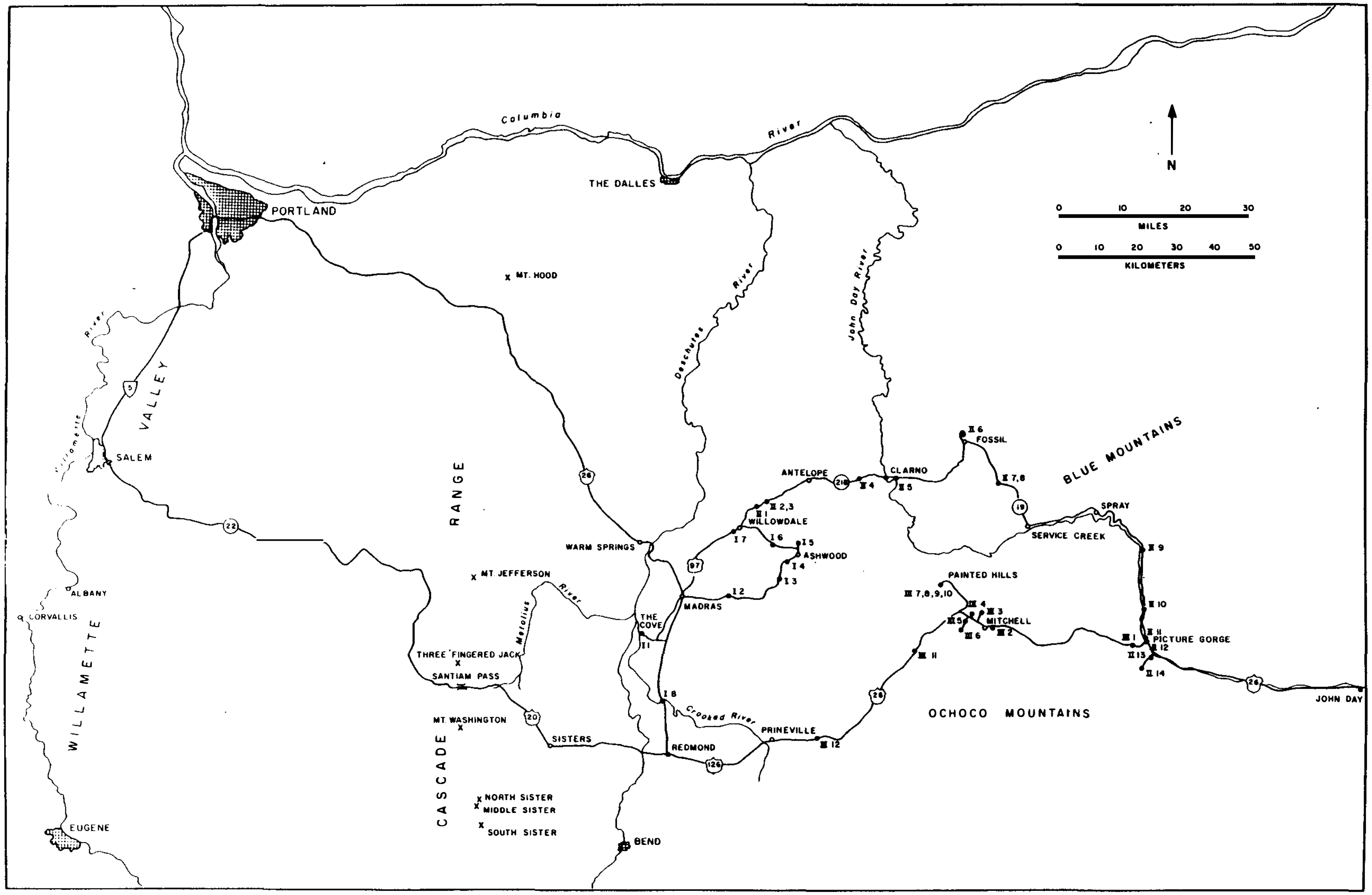
00.0 Start at corner of 5th St. and B St. in Madras, proceed east on B St. traveling through the Deschutes Formation.

05.3 Outcrop of welded tuff, lower part of Member H, John Day Formation. Outcrops of both Deschutes and John Day Formations are exposed in road cuts for next 3.6 miles.

08.9 STOP 1-2: Intracanyon flow of diktytaxitic olivine basalt caps ridge on left side of road. The flow originated from a small shield volcano visible on the flat surface to the east, entered the valley of the ancestral Hay Creek at this point, and flowed approximately 15 miles to the north toward the Deschutes River. Hay Creek has cut a new valley nearly 800 feet deep parallel to the intracanyon flow. At this point the basalt flow rests on the basal ash-flow tuff of Member G of the John Day Formation. This tuff, which is a distinctive marker unit, contains 10 to 20 percent of euhedral soda sanidine crystals typically mantled with myrmekite.

10.0 Road junction - continue straight ahead.

10.4 Road junction - take left-hand fork.



INDEX MAP OF NORTH-CENTRAL OREGON, SHOWING ROUTE OF TRAVEL.

MILES	
13.3	Lithophysal ash-flow tuff of Member E of John Day Formation exposed in road cut.
15.2	Bedded tuffs of Member F of John Day Formation in road cut on left. Red and gray tuffs of Member F exposed on hillside south of road.
17.6	Lithophysal ash-flow tuff of Member E of John Day Formation forms west-dipping hogback. Tuff exposed in road cut on right side of road. Tuff rests on trachyandesite of Member B of John Day Formation.
19.4	STOP 1-3: Viewpoint, looking west. In the foreground the ash-flow tuffs of the John Day Formation strike northeast and dip gently to the northwest. In the middle distance the John Day Formation is overlain by Columbia River basalt, which in turn is overlain by the flat-lying sediments and lava flows of the Deschutes Formation along the east foot of the Cascade Range. The strato-volcanoes of the High Cascades dominate the skyline.
23.7	Road junction - turn right. From the last stop the road has been running roughly parallel to the strike of the John Day Formation. At this point the road turns to the east and crosses the trachyandesite of Member B and the ash-flow tuffs of Member A.
24.6	STOP 1-4: Trachyandesite of Member B exposed in road cut. Walk down road across Member A to contact with Clarno Formation. Member A consists of upper fine-grained ash-flow tuff resting on approximately 100 feet of lapilli tuff which in turn overlies the basal ash-flow tuff. The basal tuff consists of two cooling units each approximately 20-25 feet thick. The tuff contains 5 - 10 percent of quartz, sanidine, and oligoclase crystals with trace amounts of green hornblende. The basal tuff of Member A crops out almost continuously from Grizzly on the south nearly to Fossil on the north. It also occurs in isolated outcrops along the crest of the Blue Mountain anticlinorium to the east, and probably extends as far east as Rowe Creek near Twickenham. A thin saprolite is locally developed on the top of the Clarno Formation. From here to Ashwood, lava flows and interbedded tuffs of the Clarno Formation are poorly exposed.
27.0	Ashwood junction - turn left.
28.8	Road junction - proceed straight ahead on dirt road.
30.0	STOP 1-5: Rhyolite intrusive domes of Member C of John Day Formation. These domes mark the source of the extensive rhyolite flows of Member C. This may also be the vent from which the ash-flow tuffs of Member E were erupted. Return to paved road and turn right.
33.0	Contact of John Day Formation and Clarno Formation in road cut on right. Saprolite at top of Clarno overlain by trachyandesite of Member B.
33.9	Contact of ash-flow tuff of Member E on trachyandesite of Member B of John Day Formation.
35.9	STOP 1-6: Excellent exposures of lithophysal ash-flow tuff of Member E of John Day Formation, overlying tuffs of Member D. Exposures continue along road in valley of Pony Creek.

MILES

40.8 Road crosses major fault in John Day Formation. The fault is down on the east and brings rhyolites of Member C in juxtaposition with the ash-flow tuffs of Member E.

43.6 Ash-flow tuff of Member H of John Day Formation in outcrops on left.

44.4 Road junction - turn left on paved highway (U.S. 97). On left of highway are small folds of ash-flow tuff of Member H.

45.8 STOP 1-7: Basal ash-flow tuff of Member I of John Day Formation. Tuff is 5 to 70 feet thick and is characterized by abundant blebs and fragments of black glass.

46.6 Fault in road cut on right brings Columbia River basalt against tuffaceous claystones of upper John Day Formation.

47.0 Contact of Yakima Basalt with tuffaceous claystones of Member I of John Day Formation. Slight baked zone.

48.0 Intracanyon basalt flow of Stop 1-2 is exposed on ridge top to left.

49.8 Contact of Yakima Basalt and overlying Deschutes Formation exposed in road cut.

60.0 Madras.

78.0 STOP 1-8: Gorge of the Crooked River. Valley of ancestral Crooked River was filled with basalt to level of bench on sides of canyon and then present canyon was cut through basalt.

86.0 Redmond. End of First Day.

SECOND DAY

Leave Redmond 7:30 A.M.: Proceed north on Highway U.S. 97 toward Madras.

00.0 Begin mileage at corner of 5th and B Streets in Madras. Proceed north on U.S. 97.

00.3 Road junction U.S. 126 and U.S. 97. Take right hand fork (U.S. 97).

16.9 Road junction U.S. 97 and Oregon 218. Take right hand fork (Oregon 218).

17.8 Road junction. Take right hand fork.

20.2 STOP 2-1: Yakima Basalt Flow with excellent columnar jointing.

21.7 Basalt ash-flow tuff of Member H of John Day Formation forms ledge on right-hand side of road.

22.1 Bedded tuff of John Day Member G in road cut on left.

22.6 STOP 2-2: Basal ash-flow tuff of John Day Member G. Unwelded equivalent of welded tuff at Stop 1-2. Eastward from this stop the tuff thins and grades into air-fall tuff.

MILES

23.3 STOP 2-3: Alkali basalt flow interbedded with tuffs of John Day Member F. This is an olivine-rich basalt with nearly 4 percent TiO_2. Note pegmatitic zones. Similar basalt flows in the same stratigraphic position can be traced discontinuously nearly to Fossil. Alkali olivine basalts also occur in the lower part of the formation near Service Creek and near the Painted Hills and in the upper part of the unit near Fossil. These flows were erupted from local vents now marked by dikes and accumulations of basaltic agglomerate and breccia.

25.7 Lithophysal welded tuff of John Day Member E in road cut on right. Basalt flow of Member F ahead and on the right.

26.1 Lithophysal welded tuff of John Day Member E in road cut on right.

28.0 Yakima Basalt flows on skyline to left.

28.5 Alkali basalt flow of John Day Member F in road cut on left.

30.4 Road junction at Antelope. Take right hand fork.

31.9 Trachyandesite of John Day Member B in road cut on right.

33.6 Hummocky topography on left marks landslide of Columbia River Basalt on John Day Formation.

39.5 STOP 2-4: Viewpoint. Cliff on north side of highway consists of John Day tuffs and flows of Member F overlain by welded tuff of Member H, which is capped by Yakima Basalt on skyline. Panorama to east overlooks valley of the John Day River. Iron Mountain at 11 o'clock is Yakima Basalt overlying tuffs of John Day Formation. Area along both sides of river is a huge landslide (over 40 square miles) in which great blocks of Columbia River Basalt have slumped on the John Day tuffs. Similar landslides have developed nearly everywhere that erosion has cut through the Columbia River Basalt, exposing the tuffaceous claystones of the John Day Formation. Rocks of the Clarno Formation are exposed across the John Day River at 1 o'clock in the core of the Blue Mountain anticlinorium. The John Day Formation displays marked facies changes across the anticlinorium, with ash-flow tuffs, lava flows, and lapilli tuffs on the west flank, and relatively fine-grained tuffs and tuffaceous claystones on the east. Sutton Mountain is visible at 2:30 o'clock in middle distance. It is underlain by Columbia River Basalt flows resting on the John Day Formation.

45.2 Red tuffs and claystones in base of John Day Formation are exposed in road cut on left.

45.8 Basal ash-flow tuff of John Day Member A. Same unit as tuff at Stop 1-4.

46.3 Clarno. Site of old ferry across the John Day River.

47.3 STOP 2-5: Contact between basal ash-flow tuff of John Day Member A and Clarno Formation. Discontinuous zone of claystone at top of Clarno. To the north can be seen basalt flows of John Day Member F interbedded with tuffs. Yakima Basalt overlies the John Day tuffs. Large landslide can be seen to northwest across the John Day River.

48.1 Andesite lava flows of Clarno Formation exposed on left.

MILES

48.6 Entrance to Camp Hancock on left. Site of well-known fossil beds in upper part of Clarno Formation. Fossil beds contain wide variety of vertebrate and plant fossils including a number of fossilized nuts.

49.3 Steep cliffs of mudflow (laharic) breccia in the Upper Clarno. Breccias are poorly sorted and poorly bedded and consist chiefly of andesitic detritus. The breccias are interbedded with andesite lava flows. Excellent exposures of flows and breccias can be seen in road cuts along Pine Creek.

59.8 Upper reaches of Pine Creek. Here the John Day Formation has pinched out and Columbia River Basalt rests directly on the Clarno Formation.

60.4 Top of Pine Creek summit. Columbia River Basalt overlies John Day tuffs on the skyline to the north with lavas of the Clarno exposed in the foreground.

65.7 Fossil Junction. Turn left on Highway 19. Town is named for fossils found by early settlers. Fossil plant locality behind the high school.

66.5 Highway crosses Butte Creek. Contact between John Day and Clarno Formations is 1/2 mile down Butte Creek to the west.

66.9 Red soil zone on top of Clarno Formation. Pumice lapilli tuffs of the John Day Formation at 10 o'clock.

67.5 Contact of Clarno and John Day Formations crosses highway.

68.4 Junction with old highway - turn right.

68.8 STOP 2-6: Silicic lava flow interbedded with pumice lapilli tuff of upper John Day Formation. Lapilli tuff is nearly 700 feet thick here and thins to west and east. Tuff is poorly sorted, poorly bedded and well indurated. Character and distribution of the tuff suggest a near-vent, air-fall origin. The lapilli tuff is overlain by 300 to 500 feet of massive tuffaceous claystones, containing scattered vertebrate fossils, which in turn are overlain by Yakima Basalt. Continue on old highway to junction with Highway 19.

70.9 Road junction. Turn left on Highway 19.

71.3 Exposures of upper John Day tuffs and tuffaceous claystones on right.

75.3 Fossil Junction. Continue straight ahead on Highway 19.

84.5 STOP 2-7: Summit Butte Creek Pass. Excellent exposures of Clarno andesites along crest of Blue Mountain anticlinorium.

85.8 STOP 2-8: Lunch at Shelton State Park.

88.2 Road junction. Continue straight ahead.

89.1 Contact of John Day and Clarno Formations on east side of Blue Mountain anticlinorium.

MILES

89.7 Tuffs of John Day Formation on left side of highway. Flows of Picture Gorge Basalt form steep cliffs on both sides of highway.

91.8 Contact of Picture Gorge Basalt and John Day Formation.

93.6 Service Creek flow in Picture Gorge Basalt. This distinctive flow can be recognized over a considerable area in the Service Creek-Twickenham area.

94.7 Junction. Continue straight ahead on Highway 19.

105.8 Contact of John Day Formation and Picture Gorge Basalt.

106.9 Spray.

108.5 Contact between John Day Formation and Picture Gorge Basalt.

109.1 Contact between John Day Formation and Picture Gorge Basalt.

110.1 Heppner Junction. Continue straight ahead on Highway 19.

111.3 Bedded tuffs of John Day Formation in cliffs on left side of highway.

111.9 Contact of John Day Formation and Picture Gorge Basalt.

114.0 Unusual jointing in Picture Gorge Basalt.

115.0 Contact of John Day Formation and Picture Gorge Basalt. Several inliers of John Day rocks are exposed along the river for the next five miles.

119.8 Kimberly. Continue on Highway 19.

121.1 STOP 2-9: Kimberly Dike. Dike of Picture Gorge Basalt cuts tuffs and tuffaceous claystones of the John Day Formation. This dike is part of the Monument Dike Swarm, a series of feeder dikes for the Picture Gorge Basalt. Note jointing in dike and fragments of John Day tuffs incorporated into dike along the contact.

122.2 Dikes of Picture Gorge Basalt at 1 o'clock.

123.0 Note high terraces on both sides of the John Day River.

124.4 Ash-flow tuff near middle of John Day Formation. This tuff has a wide distribution and is an excellent marker bed in the eastern facies of the John Day Formation. Based on variations in thickness and mineralogical composition, Fisher (1966) has suggested a source to the southwest.

127.0 Ash-flow tuff lying on green tuffs and claystones of John Day Formation.

127.6 Turnoff to Foree Area, John Day Fossil Beds State Park. Turn left.

128.2 STOP 2-10: Excellent exposures of middle and upper part of John Day Formation -

MILES

eastern facies. Green tuffs and tuffaceous claystones at base overlain by welded ash-flow tuff and upper buff tuffs and claystones. Capped by flows of Picture Gorge Basalt. Numerous vertebrate fossils in lower beds. Return to Highway 19 and continue south.

129.1 Basal red member of John Day Formation.

130.0 Landslide masses of Picture Gorge Basalt over John Day tuffs on left.

130.5 Cathedral Rock. A large landslide block of John Day tuff that has moved down toward the river from the cliffs to the west.

132.2 Basal red member of the John Day Formation resting on pre-Cretaceous rocks.

133.1 Munro Area, John Day Fossil Beds State Park.

134.5 Goose Rock. Cretaceous conglomerates bounded on north by the Middle Mountain Fault which brings the Cretaceous rocks in contact with the John Day Formation, the Picture Gorge Basalt, and, farther east, pre-Cretaceous metamorphics. Hilltop at 12 o'clock is capped with ash-flow tuff of Rattlesnake Formation.

136.6 STOP 2-11: Thomas Condon Viewpoint, John Day Fossil Beds State Park. (Figure 13) A typical section of the eastern facies of the John Day Formation. The basal red member is overlain by the middle varicolored member, including the cliff-forming ash-flow tuff which in turn is capped by Picture Gorge Basalt; the face is cut by a small fault.

Figure 13. Sheep Rock from Condon viewpoint. John Day Formation capped by Picture Gorge Basalt.

MILES

138.3 STOP 2-12: Picture Gorge. Type locality of the Picture Gorge Basalt. The Picture Gorge Basalt consists of a sequence of 19 south-dipping flows resting on the John Day Formation and overlain by the Mascall Formation. The basalt flows display many characteristic features: chilled basal contact, columnar jointing with well-developed colonade and entablature, scoriaceous tops, and interbeds of tuff and sedimentary rocks.

In the Picture Gorge area are found excellent exposures of other central Oregon Cenozoic rocks. Type localities of the John Day, Mascall, and Rattlesnake Formations as well as the Picture Gorge are found here. The chart below illustrates the stratigraphic succession.

Cenozoic	Pliocene	Rattlesnake Formation
	Miocene	Mascall Formation
		Picture Gorge Basalt
	Oligocene	John Day Formation
	Eocene	Clarno Formation
Mesozoic	Cretaceous	Goble Creek Formation (Conglomerates at Goose Rock)
Pre-Cretaceous		Serpentinites, metaconglomerates, and phyllites

138.5 Junction Highway 19 and U.S. 26. Continue straight ahead on U.S. 26.

140.2 Rattlesnake Creek. The buff-colored sediments in the foreground belong to the Mascall Formation, which on the ridge to the right is capped by gravels and welded tuff of the Rattlesnake Formation.

141.1 Mascall Ranch, turn right on gravel road.

141.5 Turn right on dirt road to viewpoint.

141.7 STOP 2-13: Westward from this vantage point it is possible to look into the type localities and see typical development of rocks comprising the John Day, Picture Gorge, Mascall, and Rattlesnake Formations. To the east looking up the valley of the John Day River, terraces of Mascall and Rattlesnake are visible on either side and on the far horizon the Aldrich and Strawberry Mountains can be seen. Return to gravel road and turn right.

142.7 Junction with Antone road. Keep straight ahead.

143.2 STOP 2-14: Rattlesnake Ignimbrite Tongue resting on the Lower Fanglomerate Member. To the left can be seen a poor outcrop of Mascall overlain in turn by the Lower Fanglomerate Member of the Rattlesnake, the Ignimbrite Tongue and the Upper Fanglomerate Member.

MILES

143.4 Turn around. Note that the Mascall has been cut out and the Rattlesnake rests directly upon Picfure Gorge Basolt. Picture Gorge basalts dip to the north here while in Picture Gorge they dip south. The axis of the John Day Syncline lies to the north of this position. Return to U.S. 26.

146.0 Junction with U.S. 26. Turn right toward John Day.

150.0 Dayville.

157.0 The prominent vertical plates visible on the right in steep slopes below the pediment are Picture Gorge flows tilted vertically in the north limb of the Aldrich Mountain Anticline. The John Day Fault follows the base of the steep slope in which the plates are exposed.

163.5 Junction - Fields Creek Road. The John Day Foult passes through the Mascall Formation in this area. In road cuts south of the main highway dip changes can be observed going from the prevailing gentle south to steep north. One thousand feet to the south vertical Picture Gorge basalts are exposed. The Aldrich Mountains to the south consist largely of a sequence of Mesozoic sediments and volcanics.

174.0 Mount Vernon.

175.4 Holliday Rest Area. The John Day Fault runs just south of this area.

180.0 John Day. End of Second Day.

THIRD DAY

00.0 Start at the junction of Highway 19 and U.S. 26, 38 miles west of John Day. Drive west on U.S. 26.

01.5 STOP 3-1: Mascall Formation crops out at road level; overlain by Rattlesnake on the ridge tops. The Mascall lies on a dip slope of Picture Gorge Basalt which can be seen rising to the skyline on the north side of Rock Creek.

03.7 Picture Gorge Basalt in road cut. The Mascall-Picture Gorge section is repeated here at least three times by WNW trending faults.

04.6 Note large slump block of Picture Gorge at 12 o'clock.

05.1 Small patch of John Day overlain by Picture Gorge.

06.3 Clarno breccias and flows, poorly exposed.

09.5 Clarno breccia on right.

12.7 Picture Gorge Basalt in road cuts.

16.5 Junction with Antone road. Rattlesnake Ignimbrite Tongue on both sides of highway, resting on Picture Gorge at the right. Continue on U.S. 26.

MILES

17.3 Ridge crest to south (left), tree-covered Ochoco Basalt resting on Rattlesnake. (Ochoco is the name given by W.D. Wilkinson for post-Rattlesnake volcanics)

20.2 John Day Formation in road cut, Rattlesnake ignimbrite on hill to the right.

23.1 Rattlesnake Ignimbrite Tongue caps ridge to the south (left). This is the westernmost occurrence of this member in the John Day drainage.

24.7 Keyes Summit. Keyes Mountain, an exhumed Oligocene volcano composed of Upper Clarno flows and breccias, can be seen at 2 o'clock. Road cuts and outcrops for the next six miles will expose Upper Clarno rocks.

31.0 STOP 3-2: Clarno mudflow breccia with angular blocks of andesite up to 20 feet in diameter overlain by platy andesite flow rocks.

31.9 Junction with Service Creek road (Highway 207); turn right on 207. The road cut on the right exposes Hudspeth mudstones. Bailey Butte on the left side of the road is a Clarno andesite sill intrusive into the Hudspeth.

32.0 Sutton Mountain at 12 o'clock is formed of multiple flows of Picture Gorge Basalt.

34.7 Turn around. Meyers Canyon to the west. On the skyline to the south are the Ochoco Mountains and Mt. Pisgah; the conical butte in the middle distance is White Butte, a Clarno hornblende andesite intrusion. The bedrock in the immediate vicinity is east-dipping Hudspeth mudstone and the white ash in the gulley to the west is an alluvial deposit of Mazama (?) ash.

35.2 STOP 3-3: Walk down Meyers Canyon to the west. Hudspeth mudstones and sandstones dipping east are first encountered. Plant fragments, pelecypods and gastropods are locally present - age Albian. Contact with Permian metasediments can be seen on the south side of the gulley. Phyllites, marbles, and blueschist can be collected from the metasediments. Return to U.S. 26.

38.6 Junction with U.S. 26, turn right.

39.4 Contact of Bailey Butte sill with mudstone.

39.5 Junction, turn right on Old U.S. 26.

40.1 Approximate axis of the Mitchell Anticline.

40.3 Floodplain of Bridge Creek and two high-level terraces on left.

40.7 Good outcrop of Hudspeth mudstone capped with high-level gravel; andesite dike on left in stream bed.

41.0 STOP 3-4: Intrusive dikes in Hudspeth mudstones. Dark basalt dike with horizontal jointing and an andesite ring dike complex with a breccia zone in the center. Some associated radial dikes of andesite can be seen. Note soft sediment deformation and concretions in the mudstone. Turn around. Return to U.S. 26.

MILES	
42.5	Junction U.S. 26, turn right.
43.8	Andesite dike cutting Hudspeth mudstone in road cut.
44.1	Junction, turn left on Gable Creek Road.
44.4	Gable Creek conglomerate on right along Gable Creek.
45.5	Andesite sill on left.
46.1	Mitchell Fault.
46.5	Black Butte at 12 o'clock. A sill of Clarno hornblende andesite intruding Cretaceous sediments.
46.7	Junction, turn right on trail.
46.8	STOP 3-5: Walk out to viewpoint. The Mitchell Fault is visible to the north where Gable Creek conglomerates are cut off. Other good exposures of Gable Creek conglomerate members are visible from here. Return to gravel road.
46.9	Junction, Gable Creek Road, turn right.
47.4	Road fork, straight ahead.
47.6	Road fork, straight ahead.
48.0	On left, mudstone overlain by conglomerate.
48.3	STOP 3-6: Viewpoint. To the southeast, Gable Creek tongue 4 can be observed pinching out into shale. Conglomerate crosses the road.
48.4	Turn around and return to U.S. 26.
54.4	Junction U.S. 26, turn left.
54.9	Gable Creek conglomerate dipping to the west.
55.2	Contact of Clarno with Cretaceous conglomerate, regolith at contact.
55.3	Junction with Bridge Creek Road, turn right. Sargent Butte at 11 o'clock is a rhyolite intrusion.
56.0	Small landslide of rhyolite on left.
56.2	Clarno flows and tuffs along highway.
56.6	Upfaulted block of Gable Creek conglomerate on the right.
56.9	Mouth of Meyers Canyon, typical Lower Clarno flows in road cut.

MILES

57.7	Contact of Clarno and John Day Formations exhibits the red basal tuff of the John Day. Travel along the contact.
57.9	Inliers of Clarno form small hills surrounded by John Day rocks.
58.6	Alkali olivine basalt outcrop, possibly of John Day age.
60.9	Junction, turn left into Painted Hills State Park.
61.5	Small fault in John Day on left.
62.0	Junction, turn left to viewpoint.
62.5	STOP 3-7: Viewpoint, looking east note Sutton Mountain capped by Picture Gorge Basalt flows with John Day tuffs and sediments dipping northeast. The thick flow in the lower part of the Picture Gorge section should be the Service Creek flow. Outcrops of Clarno Formation can be observed to the south. The ash-flow tuffs of the middle John Day Formation can be seen to the northeast. Turn around.
63.0	Junction, turn left.
63.7	Junction, turn right.
64.2	STOP 3-8: View of John Day dipping east under Picture Gorge Basalt. Two cooling units of the John Day ash-flow tuffs can be seen as resistant lenses. Inliers of Clarno (?) rhyolite can be examined here. Turn around.
64.6	Junction, turn right.
64.9	STOP 3-9: Examine rhyolite inliers.
65.3	STOP 3-10: John Day fossil plants. Turn around and return to U.S. 26.
73.5	Junction U.S. 26, turn right. Sargent Butte at 12 o'clock.
74.5	Clarno andesite in road cut.
75.0	Clarno melabasalt in road cut on right. Black Butte, a conical hill formed from a thick Clarno andesite sill, at 10:30 o' clock.
76.9	Clarno andesite dike.
77.4	Cretaceous sediments on right.
77.6	Crossing Mitchell Fault; Clarno to the north, Cretaceous sediments to the south.
78.5	Clarno intrusive andesite on left.
78.9	Clarno intrusive andesite on right.
79.2	Junction old Ochoco Highway, continue on U.S. 26.

MILES

80.1	Contortion of Cretaceous mudstone exposed in road cut is probably due to drag on the limb of a snycline in Cretaceous rocks.
80.6	Approximate location of synclinal axis.
81.0	Interesting angular relationship of conglomerate on mudstone formed by a slide block of Cretaceous sediments.
81.3	Clarno faulted against Cretaceous conglomerate on right.
82.1	Clarno andesite flows and tuffs in road cuts.
83.4	STOP 3-11: Clarno tuffaceous sediments with fish scales and plant fragments intruded by melabasalt exhibiting segregation bands. Clarno in all road cuts up to Ochoco Summit. On the west side of the summit in the Marks Creek drainage Clarno exposures are generally poor and widely separated.
118.5	Ochoco Reservoir on left.
120.4	STOP 3-12: John Day ash-flow tuff exhibiting secondary flowage after original emplacement.
121.5	Pleistocene basalt on skyline to left.
124.0	John Day rhyolite ash-flow tuff on right.
127.0	Prineville, 3rd and Main Streets.

FIELD TRIP NO. 2

VOLCANIC AND INTRUSIVE ROCKS OF THE CENTRAL PART OF THE OREGON COAST RANGE

BY

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Table 1. Average chemical composition of volcanic and intrusive rocks of the central part of the Oregon Coast Range (averages recalculated water-free).

VOLCANIC ROCKS

	Lower and middle Eocene		Uppermost Eocene			Middle Miocene	
	Siletz River Volcanics		Basalt of Yachats	Basalt of Cascade Head	Camptonite	Depoe Bay Basalt	Cape Foulweather Basalt
	1	2	3	4	5	6	7
SiO_2	49.0	48.2	51.4	47.1	41.7	55.7	51.9
Al_2O_3	14.5	16.0	17.6	15.5	12.7	14.0	13.9
$FeO+Fe_2O_3$	11.6	12.0	10.9	12.0	16.5	12.3	14.5
MgO	8.3	6.1	3.6	6.6	7.8	3.6	4.1
CaO	12.2	7.4	8.7	10.3	10.3	7.1	7.9
Na_2O	2.3	4.3	3.6	3.0	2.1	3.3	3.0
K_2O	0.17	1.9	1.0	1.3	2.7	1.4	1.0
TiO_2	1.6	3.3	2.6	3.3	4.4	2.0	3.0
P_2O_5	0.15	0.71	0.59	0.78	1.6	0.38	0.69
MnO	0.19	0.20	0.16	0.23	0.23	0.21	0.22
Number of analyses	3	9	20	12	4	8	11

INTRUSIVE ROCKS

	Lower upper Eocene(?)	Uppermost Eocene		Lower Oligocene	Mid-Oligocene		
	Albitized Diabase	Hornblende Camptonite	Biotite Camptonite	Nepheline Syenite	Granophyric Gabbro		
	8	9	10	11	12	13	14
SiO_2	50.0	43.2	41.0	60.2	55.1	57.2	57.4
Al_2O_3	15.1	14.1	13.1	19.0	14.1	13.1	13.4
$FeO+Fe_2O_3$	12.3	14.8	16.5	6.0	13.5	14.3	14.7
MgO	5.2	5.6	7.6	0.22	2.0	1.3	1.5
CaO	10.0	10.7	10.0	1.2	5.7	5.3	5.2
Na_2O	3.6	3.7	3.6	8.6	4.9	3.7	3.0
K_2O	0.55	2.0	2.1	4.1	1.1	1.8	2.0
TiO_2	2.2	3.8	4.5	0.16	2.0	1.9	1.7
P_2O_5	0.35	1.8	1.4	0.23	0.95	0.77	0.69
MnO	0.22	0.29	0.21	0.23	0.23	0.28	0.27
Number of analyses	17	5	3	11	2	3	5

1. Tholeiitic basalt from lower part of Siletz River Volcanics (Snavely and others, 1968, Table 3).
2. Alkalic basalt from upper part of Siletz River Volcanics (Snavely and others, 1968, Table 7, cols. 14 and 15, and Table 8, cols. 1-3 and 4a-7a).
3. Basalt near Yachats, Waldport, Tidewater, and Mapleton quadrangles (Snavely and others, 1969, Table 1)
4. Basalt near Cascade Heads, Hebo quadrangle (Snavely and others, 1969, Table 1)
5. Camptonitic volcanic rocks, lower Siletz River, Euchre Mtn. quadrangle (Snavely and others, 1969, Table 1)
6. Depoe Bay Basalt, northwestern Oregon (Snavely and others, 1973, Table 2)
7. Cape Foulweather Basalt, northwestern Oregon (Snavely and others, 1973, Table 2).
8. Albitized diabase sills and dikes, Euchre Mountain, Valsetz, and Grande Ronde quadrangles.
9. Hornblende camptonite sills and dikes, Euchre Mountain quadrangle.
10. Biotite camptonite dikes, Euchre Mountain quadrangle.
11. Nepheline syenite sills, dikes and stock, Tidewater and Waldport quadrangles.
12. Chilled margin basalt, Marys Peak sill, Marys Peak quadrangle.
13. Chilled margin basalt, Cedar Creek sill, Euchre Mountain quadrangle.
14. Chilled margin basalt, Stott Mountain sill, Euchre Mountain and Valsetz quadrangles.

VOLCANIC AND INTRUSIVE ROCKS OF THE CENTRAL PART OF THE OREGON COAST RANGE[1]

Igneous activity forms major chapters in the Tertiary geologic history of western Oregon and Washington. The genesis of the volcanic and intrusive rocks is of more than local interest as the magmas that gave rise to these igneous rocks were generated near the boundary of the tectonically active Pacific and North American plates. The area of this field trip in the central part of the Oregon Coast Range (Plate 1, in pocket) not only provides a representative section of all the volcanic sequences and igneous rocks exposed elsewhere in the Coast Range but also contains alkaline rocks that are rare or absent in adjacent areas.

Only a brief geologic summary is given here because the geology of the central part of the Oregon Coast Range has been described recently by Snavely, MacLeod, and Rau (1969), and detailed geologic maps of this area have been placed on open file (Snavely, MacLeod, and Wagner, 1972 a, b, c). In addition, reports by Snavely and MacLeod (1971) and Lund (1972) give descriptions of the coastal geology for the benefit of the general public.

The oldest rocks in the Oregon Coast Range are submarine basaltic pillow lavas, breccia, and tuff, and associated basaltic sedimentary rocks of early and early-middle Eocene age. In the central part of the Coast Range they are referred to as the Siletz River Volcanics (Snavely and Baldwin, 1948), in the southern part as the volcanic rocks of the Umpqua Formation (Diller, 1898), and in the northern part as the lower part of the Tillamook Volcanics (Warren, Norbisrath, and Grivetti, 1945); correlative rocks in the Coast Range and Olympic Mountains of Washington are assigned to the Crescent Formation (Arnold, 1906). Most of these lower and middle Eocene submarine volcanic rocks are low-potassium tholeiitic basalts (Table 1, col. 1) of relatively uniform composition. They are virtually identical in chemical composition with ocean ridge basalts (Snavely, MacLeod, and Wagner, 1968), and we interpret them to be oceanic crust that has been accreted onto the continental margin. This interpretation is consonant with the apparent absence of older rocks in the Coast Range and the relatively thin crust in this region (Berg and others, 1966); however, ultramafic rocks typical of ophiolite sequences in other areas have not been found.

The basaltic rocks in the upper part of the Siletz River Volcanics differ both in composition and environmental setting from those in the lower tholeiitic part (Snavely, MacLeod, and Wagner, 1968). In the upper part they consist of alkalic basalt (Table 1, col. 2), tholeiitic basalt, feldspar-phyric basalt, ankaramite, and picrite that occur as breccia, lapilli tuff, and tuff, and less abundant pillow flows. They were erupted in relatively shallow water and appear to represent a late differentiated sequence. Locally, as near Ball Mountain, the volcanic rocks accumulated in sufficient thickness to form islands where basalt was erupted subaerially. In places pillow lavas are interbedded with fossiliferous basaltic sandstones and conglomerates that were deposited near the strand line of this volcanic island. The mapped shape of this volcanic accumulation (Plate 1, in pocket) and the fact that the younger sedimentary rocks both buttress out against its flanks and extend nearly horizontally across the top suggest that the island was truncated by erosion to form a seamount before it was downwarped and buried by marine sedimentary rocks. The wide variation in chemical composition of the basaltic rocks in the upper part of the Siletz River Volcanics and their common alkaline character suggest a similarity to volcanic rocks of present-day seamounts and islands in the Pacific Basin.

The Siletz River Volcanics is overlain by the Tyee Formation (Diller, 1898), a thick sequence of rhythmically bedded sandstone and siltstone of middle Eocene age. The graded sandstone and siltstone beds that make up this unit are turbidite deposits and had their provenance in the Klamath Mountains, 100 to 150 miles to the south (Snavely, Wagner, and MacLeod, 1964). The Tyee Formation underlies most of the eastern part of the map area (Plate 1) and along the crest of the Coast Range is more than 6,000 feet thick. However, near Ball Mountain where the Tyee overlies the seamount of the Siletz River Volcanics, the Tyee is less than 1,000 feet thick. North of the seamount the sandstone of the Tyee interfingers laterally with deep-water marine pelagic siltstone.

[1]Publication authorized by the Director, U.S. Geological Survey.

In the map area (Plate 1) the Tyee Formation grades upward into marine siltstone with minor glauconitic sandstone of the Yamhill Formation. The Yamhill Formation (Baldwin and others, 1955), of late middle and early-late Eocene age, contains a few thin beds of lapilli tuff and breccia near Saddleback Mountain in the northeastern corner of the map area. In the Tillamook Highlands farther to the north, a thick sequence of marine lapilli tuff and tuff breccias of the same age attests to volcanism in early-late Eocene time. A 500-foot-wide diabase dike near Grande Ronde and thick albitized diabase sills (Table 1, col. 8) that underlie Saddleback Mountain may be related to this period of igneous activity.

A regional unconformity separates the Tyee and Yamhill Formations from the overlying Nestucca Formation (Snavely and Vokes, 1949) of latest Eocene age, which consists of thin-bedded marine tuffaceous siltstone with interbedded arkosic and glauconitic sandstone and tuff beds. Regional volcanism in latest Eocene time locally produced thick sequences of volcanic rocks that interfinger laterally with the Nestucca Formation.

The upper Eocene volcanic rocks were erupted from many local vents to form low shield-like accumulations composed largely of subaerial basalt flows 10 to 20 feet thick. Because these basalts were initially erupted on a shallow shelf, pillow basalt and tuff breccia and marine basaltic conglomerate and sandstone are present at the base and along the fringes of the volcanic piles. The upper Eocene volcanic rocks that form the rugged coastal area between Cape Perpetua and Heceta Head in the southwestern part of the map area (Plate 1) are informally referred to as the basalt of Yachats. Correlative volcanic rocks crop out along the lower Siletz River in the northwestern part of the map area and at Cascade Head, 30 miles north of Newport (Snavely and Vokes, 1949). Upper Eocene volcanic sequences also compose the upper part of the Tillamook Volcanics (Warren, Norbisrath, and Grivetti, 1945), northeast of Tillamook, and the Goble Volcanics (Wilkinson, Lowry, and Baldwin, 1946), along the Columbia River about 45 miles north of Portland.

Typically, the volcanic rocks near Yachats consist of porphyritic basalt and basaltic andesite that are quartz normative and characterized by a relatively high alkali, alumina, and titanium content (Table 1, col. 3). These rocks show a wide range in chemical composition and petrography; some dikes that cut the upper part of the sequence are of rhyodacitic composition. On variation diagrams the analyses of the volcanic rocks plot along linear trends. Together with the abundant phenocrysts that characterize the rocks, these linear variations indicate that the magma differentiated prior to eruption.

Camptonitic marine lapilli tuff and pillow lavas of latest Eocene age that crop out near the mouth of the Siletz River (Snavely, MacLeod, and Wagner, 1972a) (see Plate 1) are among the most unusual rocks in western Oregon. They are marked by low silica and high alkali, iron, titanium, and phosphorus content (Table 1. col. 5) and are strongly nepheline normative. Camptonite dikes and sills crop out over a broad area in the Euchre Mountain quadrangle (Plate 1), and some show marked differentiation.

The basaltic rocks of the Cascade Head sequence (Table 1, col. 4) also are a differentiated sequence that shows a wide range in composition. Unlike the correlative basaltic rocks near Yachats, those at Cascade Head are mostly undersaturated with respect to silica (nepheline normative).

The differences in composition between the sequences of upper Eocene volcanic rocks near Cape Perpetua, along the lower Siletz River, and at Cascade Head suggest that they were derived from separate magmas. A complex history is also suggested by a wide variation in lead isotope compositions of these upper Eocene volcanic rocks (Tatsumoto and Snavely, 1969).

Nepheline syenite and phonolite (Table 1, col. 11) sills, dikes, and a small stock occur in the Tidewater and Waldport quadrangles (Plate 1). The largest intrusive body is the 250-foot-thick sill that caps Table Mountain (Vokes, Norbisrath, and Snavely, 1949). The wide distribution of cobbles of nepheline syenite in Pleistocene terrace deposits indicates that the nepheline syenite sills were formerly much more extensive. The nepheline syenite intrusive rocks may be a late product of the period of igneous activity that produced the flow sequences at Cape Perpetua, lower Siletz River, and Cascade Head.

Marine basaltic sandstone and conglomerate of latest Eocene age overlie the basalt sequences at Cape Perpetua and Cascade Head. These basaltic sands thin rapidly away from the volcanic centers from which they were derived and are absent throughout most of the map area. Massive to thick-bedded tuffaceous siltstone and very fine-grained sandstone of Oligocene age, informally referred to as the siltstone of Alsea, overlie the upper Eocene volcanic and sedimentary rocks on the west flank of the Coast Range (see Plate 1). The ubiquitous high ash content in the Oligocene marine siltstone was derived from explosive volcanism in the ancestral Cascade Range. The ash was probably transported by rivers and streams to the former coast; some nearly pure tuff beds, however, may have resulted from ash fall directly into the marine environment.

Dikes, sills, and inclined sheets of iron-rich granophyric gabbro (Table 1, cols. 12, 13, and 14) of mid-Oligocene age crop out along the axial part of the Coast Range (Plate 1) (Snavely and Wagner, 1961). The thickest sill, about 1,000 feet thick, underlies Marys Peak 12 miles southwest of Corvallis (Baldwin, 1956). Numerous other sills, 300 to 700 feet thick, cap many of the higher peaks and upland surfaces in the Coast Range. Most of the sills show strong differentiation, with late development of ferro-granophyre and granophyre.

Sandstone and conglomerate with intercalated siltstone, tuff, and coal beds of late Oligocene and earliest Miocene age, assigned to the Yaquina Formation (Schenck, 1928) overlie the siltstone of Alsea. These sedimentary rocks are interpreted as a deltaic deposit that developed at the mouth of a river that drained through the present site of the Coast Range (Snavely and Wagner, 1963). Andesitic and dacitic clasts in conglomerate and crossbedded pumiceous sandstone of this unit were probably derived from an ancestral Cascade Range. Marine siltstone and very fine-grained sandstone of the Nye Mudstone (Harrison and Eaton, 1920; Snavely, Rau, and Wagner, 1964) of early Miocene age and sandstone and siltstone of the Astoria Formation (Packard and Kellogg, 1934; Snavely, Rau, and Wagner, 1964) of middle Miocene age overlie the Yaquina Formation. A few thick tuff beds (5 to 20 feet) in the Astoria Formation attest to continued volcanism to the east in an ancestral Cascade Range.

Three periods of basaltic volcanism occurred in western Oregon and Washington in middle and late Miocene time (Snavely, MacLeod, and Wagner, 1973). The Miocene volcanic rocks and correlative intrusive rocks crop out in a narrow belt along the northwestern Oregon coast and also crop out inland southeast and northeast of the mouth of the Columbia River in Oregon and Washington. Two of the Miocene basalt units are present in the field trip area. The oldest unit, the Depoe Bay Basalt (Snavely, MacLeod, and Wagner, 1973) (Table 1, col. 6), is the most voluminous and makes up many of the scenic headlands of the northwest coast, such as Cape Lookout and Cape Meares. Thick sills of Depoe Bay Basalt form Cape Falcon and Tillamook Head on the coast and also Mount Hebo and Mount Gauldy to the east in the Coast Range. This unit is exceptionally well exposed at its type locality at Depoe Bay, where it consists principally of isolated pillow breccia. North and east of Depoe Bay, Oligocene and Miocene sedimentary rocks are laced with a plexus of sills and dikes of basalt, breccia, and peperite that attest to the local origin of the extrusive sequence.

The middle unit of the three Miocene basalt sequences, the Cape Foulweather Basalt (Snavely, MacLeod, and Wagner, 1973) (Table 1, col. 7), overlies the Depoe Bay Basalt in several localities along the coast between Newport and the Columbia River, and dikes and sills related to this basalt are common near the coast. The most extensive exposure of this unit is at the type locality, Cape Foulweather (Plate 1), about 10 miles north of Newport, where it consists chiefly of rudely jointed breccia, tuff breccia, and minor thin flows that are cut by related dikes, sills, volcanic necks, and irregular intrusive bodies. The basalt sequence at Cape Foulweather is largely of subaerial origin, but bedded lapilli tuffs and breccia that are exposed 2 to 4 miles north of Cape Foulweather probably formed a broad fringing marine apron around the subaerial volcanic center at Cape Foulweather. Yaquina Head (Plate 1), 2 miles north of Newport, also is underlain by flows and breccia and dikes and sills of Cape Foulweather Basalt. Dikes and sills of Cape Foulweather Basalt cut Miocene and Oligocene marine sandstone and siltstone east of the coast between Cape Foulweather and Newport and also occur farther south at Seal Rocks. The youngest of the three coastal Miocene basalt units is exposed only in the Coast Range of southwestern Washington (Snavely, MacLeod, and Wagner, 1973) where it is interbedded in sedimentary rocks of the lower part of the Montesano Formation of Weaver (1912).

During the interval of time that the three units of basalt were erupted in northwestern Oregon and southwestern Washington, voluminous eruptions that produced the Yakima Basalt occurred on the Columbia Plateau east of the Cascade Range. Some of the lava flowed westward from the plateau through the present site of the Cascade Range into western Oregon and Washington. These plateau-derived flows of the Yakima Basalt crop out in the Puget-Willamette lowlands and along the lower Columbia River. The Yakima Basalt consists of several distinctive petrochemical types (Waters, 1961; Schmincke, 1967; Wright, Grolier and Swanson, 1973). The three Miocene basalt units of coastal Oregon and southwestern Washington are virtually identical in chemical composition with three major petrochemical types of the Yakima Basalt (Snavely, MacLeod, and Wagner, 1973). They also occur in the same eruptive sequence as do their corresponding chemical types in the Yakima Basalt and are approximately the same age. These relations suggest that the three coastal basalt units are comagmatic with three basalt units in the Yakima Basalt, even though the latter were vented more than 300 miles to the east (Snavely, MacLeod, and Wagner, 1973).

The Cape Foulweather Basalt is the youngest Tertiary formation exposed in the map area. However, seismic reflection profiles and oil test wells on the adjacent continental shelf indicate the presence of a thick sequence of sedimentary rocks of post-middle Miocene age (Braislin, Hastings, and Snavely, 1971).

The Tertiary volcanic and igneous rocks that crop out in the central part of the Oregon Coast Range are further described under individual stops in the field trip guide that follows.

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Figure 1. Aerial view looking northward from Sea Lion Coves (bottom right) toward Cape Perpetua (upper left) showing the coastal area that is underlain by upper Eocene volcanic rocks. The first field trip stop is at sharp bend in U.S. 101 with large roadcut just north of buildings at Sea Lion Coves. Stop 2 is along coast on south side of Heceta Head, the headland with scenic lighthouse in center of photograph. Area of low relief on the far side of Heceta Head is underlain by siltstone of Oligocene age. Photograph courtesy Delano Photographics, Portland Oregon

ROAD LOG (First Day)

MILEAGE

Start first day of field trip at Sands Motor Lodge, Newport, Oregon. Turn south on U.S. 101 and proceed through Newport toward Coos Bay.

0	Start of mileage at junction of State Highway 20 and U.S. 101; continue south on U.S. 101.
1.0	Bridge across Yaquina Bay. Outcrops on wave-cut platform on west side of north abutment are of siltstone and fine-grained sandstone in the upper part of the Nye Mudstone of early Miocene age. Table Mountain, visible from bridge at 11 o'clock on the skyline, is capped by a 250-foot-thick nepheline syenite sill.
2.0 to 8.0	The highway passes through Pleistocene terrace deposits mantled by active and stabilized sand dunes that overlie the Nye Mudstone. The terrace deposits consist chiefly of aeolian and beach sands and wood- and plant-bearing silt and clay of fluvial and estuarine origin. Fossil wood from these terrace deposits, dated by C^{14} methods, is more than 38,000 years old. The base of the terrace is 30 to 40 feet above sea level near Newport and dips gently southward towards Seal Rocks, where it lies near sea level.
8.4	Beaver Creek. The contact of the Nye Mudstone and the Yaquina Formation is exposed along shoreline south of the creek mouth.
9.5	Small wave-washed rocks offshore are composed of Cape Foulweather Basalt of middle Miocene age.
10.2	Seal Rock State Park.
10.3	View of sills and dikes of middle Miocene Cape Foulweather Basalt exposed along shoreline, on small islands, and in road cuts (to be visited later on trip).
14.0	Bridge over Alsea Bay. The westward-sloping headland area to the south is underlain by upper Eocene volcanic rocks. Table Mountain nepheline syenite sill is visible on skyline to east. Fossiliferous tuffaceous siltstone and glauconitic sandstone of Oligocene age (siltstone of Alsea) are well exposed along north shore of bay.
15.0	Waldport.
15.2	Fossiliferous tuffaceous siltstone with interbedded dacitic tuff beds of Oligocene age crop out on left side of highway. Massive 15-foot-thick bed of mudflow breccia containing andesitic and dacitic clasts derived from Cascade Range is exposed in upper part of road cut.
22.4	Small town of Yachats rests on a Pleistocene terrace cut on upper Eocene basalt flows and basaltic conglomerate and sandstone.
23.6	Yachats River. Basalt flows cut by numerous feeder dikes that are well exposed along coast and in road cuts belong to the upper Eocene volcanic sequence (informally referred to as the basalt of Yachats). Talus breccia, terrace deposits, and dune sands locally mantle the volcanic rocks.
25.3	Cape Perpetua. The rugged headland is composed of 10- to 20-foot-thick subaerial basalt flows cut by feeder dikes. Irregularities in coastline are due to differential erosion along numerous west-trending faults, joints, and dikes.

30.1 Ten Mile Creek.

33.6 Big Creek.

34.1 This area of low relief is formed of Oligocene siltstone that overlies the upper Eocene volcanic sequence. The siltstone is downfaulted against upper Eocene basalt flows, breccia, and basaltic sedimentary rocks that form Heceta Head immediately to the south.

36.6 Devils Elbow State Park.

37.4 STOP 1. Upper Eocene basalt sequence, viewpoint on U.S. 101, 1/4 mile north of Sea Lion Cave. This stop provides an overview to the north of the upper Eocene basalt sequence that crops out from here to beyond Cape Perpetua, the headland about 12 miles distant (Plate 1 and Figure 1). Subaerial flows and breccia are exposed along logging roads and in creek beds in the coastal hills for about 7 to 10 miles inland, but the best exposures are on the wave-cut platform that is developed along most of the coast. High-frequency anomalies on aeromagnetic maps of the offshore area suggest that the volcanics extend some 10 miles west of the coast. Most of the upper Eocene basalt sequence is composed of subaerial flows 10 to 20 feet thick, such as those along the coast at Sea Lion Cave. However, at Heceta Head (the site of Stop 2) interbedded submarine breccia, isolated pillow breccia, basaltic sandstone, and conglomerate occur in the upper part of the sequence. The area of low relief north of the Heceta Head lighthouse is underlain by Oligocene siltstone that overlies the basalt sequence. A northwest-trending fault just north of Heceta Head offsets the sedimentary-volcanic contact westward beyond the shoreline. Erosion along a north-trending fault in volcanic rocks at the base of the sea cliff below this viewpoint has resulted in development of a large sea cave where sea lions migrating along the coast find shelter. The basalt sequence is about 1,500 to 2,000 feet thick and is underlain by siltstone of latest Eocene age and in this area is overlain by basaltic sandstone, conglomerate, and siltstone of latest Eocene and earliest Oligocene age. Basalt from near the top of the flow sequence south of Sea Lion Caves yielded a K/Ar date of 36 m.y.

0 Return northward on U.S. 101; start new mileage.

0.1 Talus slides along rugged coast make highway construction and maintenance difficult.

0.8 Turn left (west) into Devils Elbow State Park; Walk west, upsection, toward lighthouse. STOP 2. Upper Eocene basalt sequence, Devils Elbow. Although most of the upper Eocene basalt sequence is composed of subaerial flows, the upper part contains interbedded submarine breccia, pillow basalt, and basaltic sedimentary rocks in several places such as at Devils Elbow. Here steeply dipping, rudely bedded basaltic tuff breccia with irregularly shaped pillows and broken pillows is overlain by nearshore marine basaltic sandstone and conglomerate. The basaltic sandstone is crossbedded and has scour-and-fill channels. It is composed of grains of glassy or well-crystallized basalt, scoriaceous basalt, and plagioclase crystals. Small echinoids, echinoid spines, and bryozoans are scattered through it. The cobble and boulder conglomerate, which contains some boulders up to 8 feet in diameter, was probably formed near the base of a steep sea cliff. Several dikes cut the basaltic sandstone, conglomerate, and breccia sequence at this stop. Some bifurcate and die out up section, where they appear to intrude the submarine breccia piles that they feed. Many dikes show multiple injection; interiors are commonly very vesicular. A 2-foot-thick dike that cuts basaltic sandstone below the lighthouse is of particular interest. In places along its strike, it is inflated to an ellipsoidal shape in plan view that is twice as wide as the remainder of the dike. The dike here shows funnel-shaped banding that probably resulted from surface fountaining at about this horizon.

Figure 2. View looking north at Cape Perpetua, showing west-dipping basalt flows, 10 to 20 feet thick, typical of the upper Eocene basalt of Yachats. Stop 3 is at Devils Churn along the wave-cut platform on left.

Figure 3. Upper Eocene basalt flows cut by dikes at Devils Churn, Stop 3. The light-colored dike (arrows) that parallels coast on the far side of the churn is of latitic to rhyodacitic composition.

Continue north on U.S. 101.

7.7 Ten Mile Creek.

9.0 Bob Creek. Thin basalt flows (6 inches to 2 feet thick) and numerous northwest-trending dikes (6 inches to 10 feet thick) are exposed along coast north of creek.

11.4 View of Cape Perpetua to north. Headland is composed of west-dipping subaerial flows 10 to 20 feet thick (Figure 2).

11.8 Cape Perpetua Recreation Area Visitors Center.

12.1 Turn left (west) into Devils Churn parking lot and walk down trail to coast.

STOP 3. Upper Eocene basalt sequence, Devils Churn. The churn was produced by erosion along a fault in upper Eocene basalt flows cut by dikes (Figure 3). Note that the dikes on either side of the fault-controlled churn do not match. Several small, irregularly jointed flows with aa tops are exposed on the wave-cut platform; oxidized zones are developed at the tops and bases of some flows. Some of the northwest-trending dikes that intrude the flows have sill-like apophyses into the flows; in other areas along the coast dikes are seen to feed flows. Many of the dikes are composite and show systematic variations in texture, phenocryst content, and chemical composition. The chemical composition of the volcanic rocks that form the upper Eocene Cape Perpetua - Heceta Head sequence varies considerably. Several chemical analyses that show this variability, including analyses of flows and dikes from near Devils Churn, are shown in Table 2. Most flows contain 49 to 53 percent SiO_2 and are of basaltic composition, but a few are basaltic andesite (labradorite andesite, according to chemical classification of Rittman, 1952) or andesite. Dikes show an even greater variability in composition. They are predominantly basaltic, but several, particularly near Devils Churn, contain 60 to 68 percent SiO_2 (Table 2, cols. 5 and 6) and are of latitic and rhyodacitic chemical composition, according to the chemical classification of Rittman (1952). All flows and intrusive rocks in this sequence are quartz normative and are characterized by relatively high contents of alumina (reflecting abundant plagioclase phenocrysts) and alkalies. The coeval volcanic rocks at Cascade Head generally contain less SiO_2 (see Table 1) and are nepheline normative; coeval camptonitic volcanic rocks along the lower Siletz River contain only 40 to 45 percent SiO_2 and are strongly nepheline normative.

Depart Devils Churn; proceed north on U.S. 101.

13.2 View of wave-cut platform cut on upper Eocene basalts with thin terrace sand cover.

14.3 Yachats River.

15.2 Turn left (west) at Adobe Motel near north end of Yachats. Walk to coast and then north 200 yards along beach.

STOP 4. Uppermost Eocene basaltic sandstone and conglomerate sequence, Yachats. The upper Eocene basalt sequence is overlain at this locality by boulder conglomerate (Figure 4) of latest Eocene age. Several hundred feet of fossiliferous basaltic sandstone overlies the conglomerate. The conglomerate, which contains boulders as much as 10 feet across, is formed on a very irregular surface cut in basalt flows, breccia, and dikes. The flows commonly have oxidized zones, and some aerodynamically shaped bombs occur in the breccia, indicating they are of subaerial origin. The conglomerate-sandstone unit has been traced to Eckman Creek, 2 miles southeast of Waldport, where it decreases in

Figure 4. Basalt-boulder conglomerate overlying eroded upper Eocene basalt flows and dikes north of Yachats at Stop 4. Most boulders and cobbles are subround or subangular. Hammer (circled) shows scale.

Figure 5. Quarry in small nepheline syenite stock on east end of Blodgett Peak (Stop 5). Jointing along primary flow banding is nearly vertical in center but dips less steeply on right. Nepheline syenite from quarry was used for road rock and jetty rock.

thickness. It has not been found on the north side of Alsea Bay, where marine siltstone of similar age is exposed. Similar basaltic conglomerate and sandstone units overlie many of the late Eocene volcanic sequences in western Oregon and Washington.

Proceed north on U.S. 101.

18.6 Turn right (east) on Blodgett Road (at Angel Job Corps Center sign).

22.0 Road on left goes to Blodgett Peak, which is underlain by small elongate nepheline syenite stock; continue east on main road.

22.4 STOP 5. Nepheline syenite, east Blodgett Peak quarry. Quarry exposure shows part of small porphyritic nepheline syenite stock (Figure 5) that extends westward to Blodgett Peak. Anorthoclase phenocrysts in the nepheline syenite have been oriented by flowage. This flow banding generally parallels contacts with sedimentary and volcanic rocks. The nepheline syenite body was apparently injected forcibly and bowed up the sedimentary and volcanic rocks into a domal structure. The outcrop of nepheline syenite may be only the small surface exposure of a larger body at depth. Other nepheline syenite bodies crop out to the east in the Tidewater quadrangle, where they intrude the Tyee Formation. The nepheline syenite is composed of anorthoclase, K-feldspar, nepheline, analcime arfvedsonite, aegirine, and opaque minerals. Chemical analyses of nepheline syenite from Blodgett Peak and Table Mountain are shown in Table 3. The strongly undersaturated nepheline syenite appears to represent a late continuation of the period of volcanism that produced the upper Eocene basalts. The upper Eocene basalts at Cascade Head and camptonite flows along the lower Siletz River are also undersaturated with respect to silica. The upper Eocene basalts in the Cape Perpetua-Heceta Head area, however, are mostly quartz-normative and probably represent separately derived magma. A close areal association of nepheline syenite with camptonite and shonkinite in the Tidewater quadrangle suggests they may be comagmatic. A nepheline syenite dike from Indian Creek in the Mapleton quadrangle has been dated by K/Ar methods as 34 m.y. old, or early Oligocene.

Return to U.S. 101 by same route.

26.2 Junction U.S. 101; turn right (north).

30.9 Bridge over Alsea Bay. On north side of bay, tuffaceous siltstone and glauconitic and arkosic sandstone of Oligocene age are exposed in banks. Ash in the siltstone was apparently derived from explosive volcanism in the ancestral Cascade Range.

35.6 Turn left (west) to Seal Rock State Park parking lot. Proceed down trail at south end of parking lot to beach.

STOP 6. Cape Foulweather Basalt intrusives, Seal Rocks. The basalt exposed here at Seal Rocks belongs to the younger of two sequences of Miocene basalt that crop out along the Oregon coast between here and Astoria. A still younger Miocene flow unit occurs in southwestern Washington. The sills and dikes of Cape Foulweather Basalt at Seal Rocks intrude sandstone of the Yaquina Formation, here of latest Oligocene age. The sill at the headland is about 80 feet thick and is concordant with the sandstone it intrudes. Farther north, however, it becomes discordant and in the farthest north exposures is nearly vertical and strongly discordant. Wave-washed islands offshore are probably also basaltic intrusive rocks. The Cape Foulweather Basalt is characterized by sparse but distinctive yellowish labradorite phenocrysts that distinguish it from the aphyric Depoe Bay Basalt, which is slightly older. The Yaquina Formation is exposed along the shoreline and is a deltaic deposit of sandstone, conglomerate, siltstone, and tuff that has a lenslike outcrop

Table 2. Chemical anlyses of upper Eocene volcanic rocks from the Cape Perpetua-Heceta Head area. Analyses are recalculated water-free to 100 percent.

	1	2	3	4	5	6
SiO_2	49.1	50.1	54.3	57.7	64.0	68.6
Al_2O_3	18.2	17.2	17.5	17.2	16.9	15.8
$FeO+Fe_2O_3$	11.2	12.0	9.6	8.5	5.5	3.2
MgO	4.5	4.7	2.8	2.4	1.0	0.20
CaO	10.2	9.4	7.1	5.8	3.0	2.3
Na_2O	3.1	2.9	3.8	4.4	4.2	4.7
K_2O	0.39	0.78	1.9	2.0	2.8	2.8
TiO_2	2.9	2.7	2.2	1.5	0.75	0.74
P_2O_5	0.45	0.39	0.61	0.75	0.13	0.41
MnO	0.15	0.14	0.13	0.11	0.18	0.10

1. Breccia, SE¼, Sec. 33, T. 16 S., R. 12 W., Heceta Head quadrangle, (Stop #2)
2. Flow, SE¼, Sec. 3, T. 15 S., R. 12 W., Waldport quadrangle (Stop #2)
3. Flow, NE¼, Sec. 3, T. 15 S., R. 12 W., Waldport quadrangle (Stop #2)
4. Dike, NW¼, Sec. 3, T. 15 S., R. 12 W., Waldport quadrangle (Stop #3)
5. Dike, NW¼, Sec. 3, T. 15 S., R. 12 W., Waldport quadrangle (Stop #3)
6. Dike, NW¼, Sec. 3, T. 15 S., R. 12 W., Waldport quadrangle (Stop #3)

Table 3. Chemicol analyses of nepheline syenite from Blodgett Peak (Stop 5) and Table Mountain. Analyses recalculated water-free to 100 percent.

	Blodgett Peak		Table Mountain	
	1	2	3	4
SiO_2	58.2	59.0	60.5	60.6
Al_2O_3	19.0	18.9	18.9	19.0
$FeO+Fe_2O_3$	7.6	7.5	5.0	5.0
MgO	0.29	0.20	0.10	0.10
CaO	1.8	1.3	1.2	1.2
Na_2O	8.8	8.2	9.2	9.1
K_2O	3.6	4.0	4.3	4.3
TiO_2	0.16	0.25	0.13	0.14
P_2O_5	0.25	0.41	0.16	0.16
MnO	0.22	0.25	0.23	0.22

1. NW¼, Sec. 18, T. 14 S., R. 11 W., Waldport quadrangle (Stop #5)
2. NW¼, Sec. 18, T. 14 S., R. 11 W., Waldport quadrangle (Stop #5)
3. SE¼, Sec. 36, T. 12 S., R. 10 W., Tidewater quadrangle
4. SE¼, Sec. 36, T. 12 S., R. 10 W., Tidewater quadrangle

pattern (Plate 1); it is thickest northeast of Newport and thinnest here at Seal Rocks at the south end of its outcrop area and at Siletz Bay at the northern end. The sandstone displays crossbedding and scour-and-fill channels. Andesitic and dacitic clasts are common in conglomerate interbeds and were probably transported westward across the present site of the Coast Range by a river that had its headwaters in the present site of the western Cascade Range. The base of the terrace deposits here is near sea level and rises gently northward to about 30 to 40 feet near Newport.

Continue north on U.S. 101.

37.5 View of fossiliferous sandstone and siltstone of the Yaquina Formation behind old mill north of Beaver Creek.

44.3 Bridge over Yaquina Bay. The Marine Science Center of Oregon State University is located on spit east of bridge.

Continue north on U.S. 101 through Newport.

47.4 Sandstone of the middle Miocene Astoria Formation crops out below terrace deposits.

50.0 View of Cape Foulweather, type locality of the Cape Foulweather Basalt. The small headland at Otter Rock, below and south of Cape Foulweather, is formed of sandstone of the Astoria Formation. Highway is cut on terrace deposits that overlie west-dipping sandstone of the Astoria Formation; both are subject to landsliding.

52.0 Beverly Beach State Park.

53.0 Otter Rock turnoff. Continue north on U.S. 101.

54.3 Small neck of Cape Foulweather Basalt with radiating columnar joints is exposed in small quarry on east side of highway near bend.

54.6 Turn left (west) on road to Otter Crest View Point.

54.8 STOP 7. Cape Foulweather Basalt, Otter Crest View Point. Otter Crest and much of the coastal area for 5 miles to the north are underlain by the Cape Foulweather Basalt of middle Miocene age. This unit is the younger of two middle Miocene volcanic sequences that are exposed along the northern part of the Oregon coast. Flow breccia, extrusive breccia, and intercalated massive flows constitute the bulk of the Cape Foulweather Basalt at Otter Crest, whereas farther from the vent area, water-laid lapilli tuff predominates. Numerous dikes, sills, and small plugs intrude the breccia near Otter Crest, indicating that this area was a local center of Miocene volcanism. Two ring dikes and several radial dikes are exposed at low tide on the wave-cut platform just south of Otter Crest (Figure 6). The Cape Foulweather Basalt also crops out at Yaquina Head, about 5 miles south of Otter Crest, and on the large island (Otter Rock) immediately west of Otter Crest. The two smaller islands immediately to the south of Otter Crest (Gull Rock and Whaleback), however, are composed of subaerial basalt flows of the Depoe Bay Basalt, which is slightly older than the Cape Foulweather Basalt but also of middle Miocene age. Petrochemical studies of the Cape Foulweather Basalt from its type locality at Cape Foulweather and other areas along coastal northwestern Oregon show that it has a relatively uniform composition (Snavely, MacLeod, and Wagner, 1973). Two chemical analyses of Cape Foulweather Basalt are listed in Table 4 (cols. 4 and 5). The Cape Foulweather Basalt can readily be distinguished from the slightly older Depoe Bay Basalt on the basis of petrochemistry, and it can be identified in the field on the basis of its sparse but ubiquitous labradorite phenocrysts, which do not occur in the Depoe Bay Basalt. The terrace on Otter Crest is about 500 feet above sea level and is one of the higher of several Pleistocene terraces developed along this coastline. Constructional marine terraces, about 50 feet above sea level, are developed on westward-dipping sandstone and siltstone of the Astoria Formation on the two nearby headlands to the south. Immediately north of the viewpoint, sandstone of the Astoria Formation is visible at sea level. On a clear day, one can see Cascade Head 20 miles to the north, which is formed of upper Eocene basalt flows.

Return to Newport.

End of first day of field trip.

ROAD LOG (Second Day)

Start of second day of field trip at Sands Motor Lodge. Turn south on U.S. 101.

0 Start of mileage at junction of U.S. 101 and State Highway 20; turn left (east) on Highway 20 towards Toledo.

0.2 Newport is constructed on a broad Pleistocene terrace that is modified by ancient sand dunes.

0.4 Early Pleistocene terrace, 200 feet above sea level, is cut in lower Miocene Nye Mudstone.

0.6 Outcrop of Nye Mudstone. The siltstone and interbedded very fine grained sandstone of the Nye is susceptible to landsliding, and periodic extensive reconstruction of the highway has been necessary in the past.

1.9 View to south of the Yaquina estuary. Large landslide in the Nye Mudstone occupies much of the area between the highway and bay.

2.5 Gradational contact of the Nye Mudstone and the late Oligocene Yaquina Formation. The sandstone, conglomerate, and siltstone of the Yaquina Formation are interpreted as a deltaic deposit whose thickest part lies 5 to 10 miles north of the highway.

4.1 Good exposure of Yaquina sandstone on the north side of road.

4.6 Contact between Yaquina Formation and tuffaceous siltstone unit of Oligocene age which is informally referred to as the siltstone of Alsea.

5.8 Junction Highway 229. Turn left (north) toward Siletz; road runs generally along strike in the basal part of the siltstone of Alsea.

6.8 Upper part of the tuffaceous siltstone of Alsea and basal part of the Yaquina Formation are exposed on dirt road west of highway.

9.6 Poorly exposed siltstone of Alsea (Oligocene). Beyond this point the road continues down section through siltstone of the Nestucca Formation of latest Eocene age and siltstone and glauconitic sandstone of the Yamhill Formation of late middle and early late Eocene age.

11.0 Poor exposures of the Yamhill Formation.

Figure 6. View looking south from Otter Crest (Stop 7), showing ring and radial dikes of Cape Foulweather Basalt that intrude sandstone of the Astoria Formation. Yaquina Head on the skyline is formed of basalt flows, breccia, and dikes of Cape Foulweather Basalt. Gull Rock and Whaleback, the two small wave-washed islands in upper center of photograph west of the broad beach at Beverly Beach State Park, are formed of basalt flows of the Depoe Bay Basalt.

Table 4. Chemical analyses of Miocene Depoe Bay and Cape Foulweather Basalts, Cape Foulweather quadrangle. Analyses recalculated water-free to 100 percent.

	Depoe Bay Basalt		Cape Foulweather Basalt	
	1	2	3	4
SiO_2	55.6	55.7	51.7	52.0
Al_2O_3	13.8	14.1	13.7	13.4
$FeO+Fe_2O_3$	12.7	11.6	14.3	14.5
MgO	3.5	4.1	3.9	4.0
CaO	7.1	7.5	8.3	7.9
Na_2O	3.5	3.3	3.3	3.1
K_2O	1.1	1.4	0.77	1.1
TiO_2	2.1	1.8	3.1	3.0
P_2O_5	0.40	0.28	0.67	0.65
MnO	0.27	0.19	0.22	0.23

1. Pillow, Stop #14, SW¼, Sec. 5, T. 9 S., R. 11 W. (Snavely, MacLeod, and Wagner, 1973, Table 4).
2. Dike, Stop #14, NW¼, Sec. 9, T. 9 S., R. 11 W., (Snavely, MacLeod, and Wagner, 1973, Table 4).
3. Breccia, Stop #14, SW¼, Sec. 5, T. 9 S., R. 11 W., (Snavely, MacLeod, and Wagner, 1973, Table 6).
4. Neck, Stop #14, SE¼, Sec. 29, T. 9 S., R. 11 W., (Snavely, MacLeod, and Wagner, 1973, Table 6).

Table 5. Chemical analyses of basaltic rocks from the upper part of the Siletz River Volcanics, Euchre Mountain quadrangle (from Snavely, Macleod, and Wagner, 1968, Table 7). Analyses recalculated water-free to 100 percent.

	1	2	3	4
SiO_2	51.3	47.1	46.3	43.4
Al_2O_3	17.5	22.1	12.0	7.1
$FeO+Fe_2O_3$	10.2	7.7	10.7	11.3
MgO	3.8	5.1	17.4	30.1
CaO	5.5	14.0	11.2	5.8
Na_2O	6.2	2.1	0.87	0.81
K_2O	1.9	0.34	0.16	0.13
TiO_2	2.5	1.3	1.1	0.88
P_2O_5	0.77	0.15	0.13	0.15
MnO	0.21	0.12	0.19	0.16

1. Alkalic basalt, SW¼, Sec. 8, T. 8 S., R. 10 W., (Stop #11).
2. Feldsparphyric basalt, SW¼, Sec. 27, T. 7 S., R. 10 W.
3. Ankaramitic basalt, SE¼, Sec. 34, T. 8 S., R. 9 W.
4. Picritic basalt, NW¼, Sec. 22, T. 8 S., R. 9 W.

12.7 Contact of the Yamhill Formation and graded sandstone and siltstone beds (turbidites) of the Tyee Formation of middle Eocene age.

13.1 Siletz River bridge. The contact between the Tyee and Yamhill Formations is well exposed along the river about 200 yards west of the bridge.

13.4 Turn right (east) at Siletz on upper Siletz road.
0 Start new mileage.

0.7 Gravel pits in low river terrace.

2.6 Excellent exposure of Tyee Formation composed of 1- to 3-foot-thick graded sandstone and siltstone beds (turbidites).

4.8 On right, note old covered bridge over Siletz River on Sams Creek Road.

7.3 Ridge on skyline to north is underlain by the Siletz River Volcanics and a granophyric gabbro sill of mid-Oligocene age.

7.8 Bridge over Siletz River at Logsden. Turn left (north) on Upper Farm Road on east side of the bridge.

8.0 Exposure of thick-bedded Tyee sandstone.

11.4 Road junction on left -- continue straight ahead on dirt road that passes beside old logging company buildings.

11.9 Approximate contact between Tyee Formation and Siletz River Volcanics which is well exposed in river bed. About 100 feet of indurated siltstone occurs above the highest tuff and lapilli tuff in the Siletz River Volcanics and below the lowest turbidite in the Tyee along the river.

12.6 Turn left (north) across bridge over Siletz River, then turn left (west) and proceed parallel to river (downstream).

13.1 STOP 8. Siletz River Volcanics, gorge of the Siletz River. Close-packed porphyritic augite basalt pillows and interbedded augite crystal tuff are exposed in road cuts and in river bed. These volcanic rocks are in the uppermost part of the Siletz River Volcanics, about 200 feet below the upper contact, and are overlain by graded deep-water marine sandstone and siltstone of the Tyee Formation. Interbedded siltstone and sandstone in the Siletz River Volcanics near this locality contain a foraminiferal and molluscan fauna of early middle Eocene age. Farther up the river, in the Valsetz quadrangle, basaltic sandstone and siltstone interbedded lower in the volcanic sequence contain foraminiferal and molluscan assemblages of early Eocene age.

The upper part of the Siletz River Volcanics consists of tuff, lapilli tuff, tuff breccia, pillow flows, and basaltic siltstone, sandstone, and conglomerate. A few massive or columnar-jointed flows separated by oxidized scoria zones that crop out near Ball Mountain are of subaerial origin and indicate that the volcanic rocks accumulated in sufficient thickness to form an island. The late-stage volcanism represented by the rocks of the upper part of the sequence was probably more explosive than that of the lower part, which consists predominantly of tholeiitic pillow basalt. Rock types in this upper unit also vary widely in composition in contrast to the lower tholeiitic part, which is relatively uniform; chemical analyses of typical rocks from the upper part of the Siletz River Volcanics are shown in Table 5.

The upper part contains a variety of rock types including alkalic basalt, feldspar-phyric basalt, ankaramite, picrite, and tholeiitic olivine basalt. Phenocrysts of augite, such as at this locality, as well as olivine and calcic plagioclase are abundant in rocks of the upper part and suggest that the magma was differentiated in shallow reservoirs prior to eruption. Return east on road to bridge over Siletz River.

13.5 Return across bridge over Siletz River; turn left (east) upstream on south side of river.

14.4 STOP 9. Granophric gabbro, gorge of the Siletz River. A large granophric gabbro dike extends from Green Mountain in the Valsetz quadrangle east of the Siletz gorge to Lambert Peak farther west (Plate 1). Near the Siletz gorge the granophyric gabbro dike rolls over within a few hundredsof feet to form a south-dipping inclined sheet that is discordant to the Siletz River Volcanics but generally concordant with the overlying Tyee Formation. A "roll-over" in the inclined granophyric gabbro sheet occurs at this stop. This sill may have extended northward 8 miles to Stott Mountain, which is capped by a 500-foot-thick sill. Other sills or inclined sheets cap many of the higher peaks, ridges, and upland surfaces in the Coast Range between latitudes 43°45' and 45°N, including Fanno Ridge, Prairie Peak, Marys Peak, and Roman Nose Mountain. They are typically 300 to 500 feet thick, although the sill at Marys Peak (Baldwin, 1956) is about 1,000 feet thick. Three K/Ar dates of minerals separated from gabbro and pegmatite indicate an absolute age of about 30 m.y. (mid-Oligocene). The granophyric gabbro is composed of plagioclase, ferroaugite, intergrown quartz and alkali feldspar, apatite, opaque minerals, and iron-rich clay minerals. Fayalitic olivine is a constituent of most granophyric gabbro but is absent in a few. Most of the sills and inclined sheets are differentiated, and bodies of pegmatitic gabbro, ferrogranophyre, and granophyre are commonly developed within them. These more silicic rocks contain the same minerals as does the gabbro but in different proportions, and the mafic minerals are more Fe-rich and the feldspars more Na- and K-rich. Typical analyses of rocks from the granophyric gabbro sill in the area between the gorge the Euchre Mountain are listed in Table 6.

At this stop, the upper contact of an inclined sheet is exposed in the small quarry where the gabbro intrudes tuff and tuff breccia and pillow lavas of the Siletz River Volcanics. Granophyric gabbro and ferrogranophyre in the upper part of the body are well exposed along the steep walls of the river. The faint layering shown by the granophyric gabbro and ferrogranophyre has been noted in the upper parts of several of the sills. The lower two-thirds of most sills and inclined sheets shows no visible layering, but petrographic and chemical studies show that they have a systematic upward variation in modal proportions, mineral compositions, and rock compositions (MacLeod, 1970). Continue upstream along the Siletz River road.

15.4 Top of granophyric gabbro sill is exposed in west bank and bottom of river.

15.5 Baked basaltic tuff of the Siletz River Volcanics overlies gabbro sill; a small north-trending fault offsets the upper contact along the river. Proceed northward through the granophyric gabbro sill. Note nearly vertical joints in the sill above the west bank of the river.

16.4 Base of inclined sheet is exposed near river level. The basaltic tuffs below the sheet are baked as much as 20 to 30 feet away from contact.

16.6 Bridge over Siletz River near Camp Gorge.

17.6 Quarry exposure of tholeiitic basalt sill of the Siletz River Volcanics. Such sills are common in bedded tuffs and basaltic sandstone in the upper part of the volcanic sequence. These tholeiitic basalt sills are generally more potassium-rich than tholeiitic basalt from the lower part of the Siletz River Volcanics.

Table 6. Chemical analyses of rocks from differentiated granophyric gabbro sills, Euchre Mountain quadrangle. Analyses recalculated water-free to 100 percent.

	1	2	3	4
SiO_2	54.7	58.0	62.3	73.4
Al_2O_3	13.3	12.9	13.0	13.1
$FeO+Fe_2O_3$	17.0	14.1	11.8	1.7
MgO	1.2	1.2	0.65	0.12
CaO	5.8	6.1	4.8	0.72
Na_2O	3.0	3.2	3.2	4.3
K_2O	1.5	1.7	2.5	4.4
TiO_2	2.5	2.0	1.1	0.26
P_2O_5	0.77	0.60	0.30	0.05
MnO	0.33	0.29	0.23	0.06

1. Cen. S½, Sec. 1, T. 9 S., R. 10 W.
2. SW¼, Sec. 16, T. 9 S., R. 9 W., (Stop #9).
3. SW½, Sec. 26, T. 8 S., R. 10 W.
4. NW¼, Sec. 16, T. 9 S., R. 9 W.

Table 7. Chemical analyses of camptonic intrusive and extrusive rocks in the Euchre Mountain quadrangle. Analyses recalculated water-free to 100 percent.

	1	2	3	4
SiO_2	40.1	42.3	39.8	40.9
Al_2O_3	11.8	13.7	12.0	13.3
$FeO+Fe_2O_3$	17.4	16.3	17.2	16.7
MgO	7.6	5.7	7.7	7.1
CaO	10.8	11.4	10.7	9.9
Na_2O	3.7	3.4	4.2	1.5
K_2O	1.8	1.6	1.4	3.9
TiO_2	4.8	3.2	4.8	4.9
P_2O_5	1.6	2.1	1.6	1.5
MnO	0.26	0.3	0.27	0.21

1. Dike, Stop #10, NE¼, Sec. 20, T. 8 S., R. 11 W.
2. Sill, SW¼, Sec. 17, T. 7 S., R. 9 W.
3. Flow, NE¼, Sec. 13, T. 8 S., R. 11 W.
4. Flow, NE¼, Sec. 13, T. 8 S., R. 11 W.

17.8 Turn around and return down river to town of Siletz.

18.4 View to east of 50-foot-thick tholeiitic basalt sill in bedded marine basaltic tuff and sandstone of the Siletz River Volcanics. Basal contact of granophyric gabbro sill is exposed high on ridge to southeast.

19.0 Siletz River bridge near Camp Gorge.

19.4 Good view of granophyric gabbro sill on west side of river.

23.1 Road junction; continue south.

26.7 Road junction; turn right across bridge at Logsden and continue toward town of Siletz.

34.5 Town of Siletz. Turn right (north) toward Kernville.
0 Start new mileage.

0.8 Bridge over Siletz River. Road follows near the upper contact of the Tyee Formation, which is well exposed along the river.

3.3 Bridge over Siletz River.

3.8 Logged conical-shaped hill on horizon to north (Euchre Mountain) is capped by a differentiated granophyric gabbro sill.

4.5 Bridge over Euchre Creek.

5.9 Excellent exposure of turbidites of the Tyee Formation.

6.4 Lunch stop at county park. Continue west.

8.3 Contact of Tyee and Yamhill Formations is exposed in river banks.

8.5 Cedar Creek; head of tidewater on the Siletz River.

9.1 Contact of Yamhill and Nestucca Formations is exposed in river.

9.8-9.9 Siltstone of the Nestucca Formation cut by clastic sandstone dikes and sill-like bodies.

13.1 Marine basaltic breccia interbed in the Nestucca Formation.

14.2 Exposure of Nestucca siltstone.

14.8 Unconformable contact between Nestucca and Tyee Formations.

16.5 STOP 10. Biotite camptonite dike, Siletz River road. Camptonite dikes, sills, and inclined sheets crop out in a large area in the northeastern part of the Euchre Mountain quadrangle (Snavely and Vokes, 1949; Snavely, MacLeod, and Wagner, 1972a) and extend east and northeast into the Valsetz and Grande Ronde quadrangles (MacLeod, 1970). Camptonitic rocks are particularly well exposed in the vicinity of Cougar Mountain (see Plate 1). These alkaline mafic intrusive rocks range from aphyric rocks rich in augite, aegerine-augite, or titaniferous augite to rocks that contain abundant large equant crystals of barkevikitic hornblende or titaniferous biotite set in a matrix containing augite, aegerine-augite, barkevikitic hornblende, alkali-feldspar, sodic plagioclase, analcime, feldspathoids, apatite, and opaque minerals. Some of the sills and dikes are differentiated and contain small pegmatitic camptonite bodies and phonolite veinlets. A sequence of camptonitic breccia, lapilli tuff, and pillows will be seen later along the lower Siletz River at Stop 12. The biotite camptonite dike at Stop 10 and several other camptonite dikes that have been mapped immediately to the west were apparently feeder dikes to the extrusive sequence at Stop 12. Chemical analyses of typical samples of camptonite are shown in Table 7. The camptonite intrusive rocks and the correlative extrusive rocks are strongly undersaturated with respect to silica (nepheline normative) and are characterized by high contents of Fe, Ti, Na, K, and P. Biotite- and hornblende-bearing camptonites were probably more water-rich than otherwise chemically similar aphyric augite camptonite. The camptonite is approximately equivalent in age to the uppermost Eocene basalt flows that form Cascade Head, 30 miles north of Newport. Although the camptonite and some of the Cascade Head basalts have many chemical similarities, the former contains considerably lower silica and more alkalies.

Continue along Siletz River road.

17.2 Steep cliffs along north side of river are held up by the Siletz River Volcanics. Breccia, tuff, and pillow basalt are well exposed along new road and are overlain by the Tyee Formation at top of hill.

18.2 Fault contact of Tyee Formation and Siletz River Volcanics.

19.1 Outcrop of thick-bedded zeolitic lapilli tuff and tuff breccia of the Siletz River Volcanics.

20.6 STOP 11. Siletz River Volcanics, Kauffman quarry (private property). Filled feeder-tube composed of columnar-jointed alkalic basalt is exposed at base of quarry. The filled tube is surrounded on the sides and top by a carapace of elongate basalt pillows (Figure 7) (Snavely, Macleod, and Wagner, 1968). The pillows and filled feeder-tube rest on fine-grained basaltic sandstone. Altered alkalic basalt (Table 5, col. 1), such as that exposed in the quarry, is common in the upper part of the Siletz River Volcanics. A small, filled feeder-tube on the east side of the quarry (formerly well exposed but now partly removed by quarrying) contains aphyric alkalic basalt at the base that grades upward into porphyritic augite basalt in the center. It formed by lava erupted from a shallow magma chamber in which crystals had settled to the base during differentiation. Feeder-tubes such as these exposed at Kauffman quarry are common in the upper part of the Siletz River Volcanics. Lava flowed through these tubes below a self-formed protective cover of pillow lava.

Continue west along Siletz River.

20.8 Contact of the Siletz River Volcanics and Tyee Formation.

21.3 Large hill to the south is Cannery Mountain, which is underlain by camptonitic lapilli tuff, breccia, and pillow lava.

21.9 Base of camptonitic extrusive sequence.

22.3 STOP 12. Camptonitic extrusive sequence, lower Siletz River. Camptonitic lapilli tuff and breccia that are cut by small camptonitic dikes and sills are exposed in small quarry beside highway and along river bank. Most of the fragmental material was originally camptonitic glass clouded with microlites, but the glass is now largely altered. Biotite and hornblende phenocrysts and microphenocrysts are sparsely distributed through the tuff and breccia. Chemical analyses of two samples of extrusive camptonite are listed in Table 7, cols. 3 and 4. Thin and often distorted siltstone interbeds in camptonitic tuff breccia

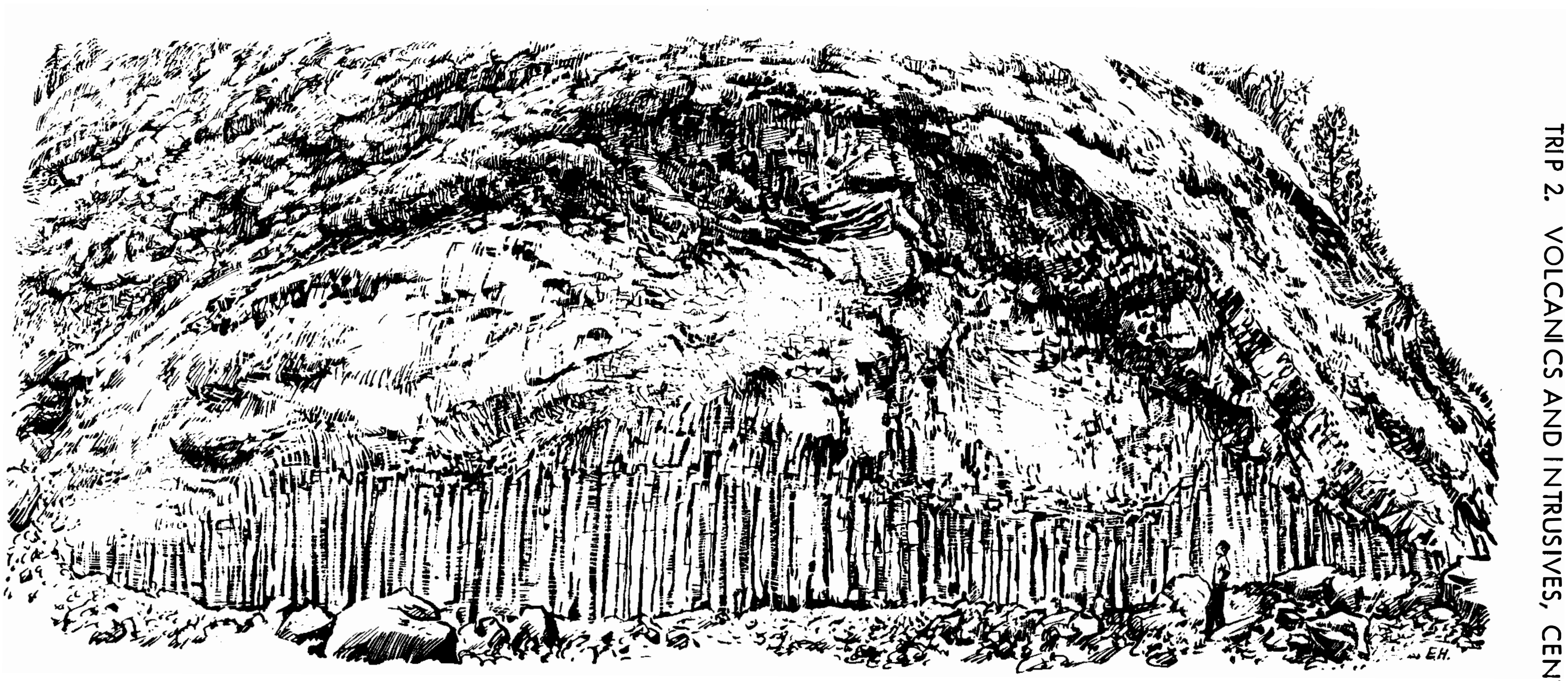

Figure 7. Filled feeder-tube in the Siletz River Volcanics at Kauffman quarry (Stop 11). Columnar-jointed alkalic basalt in the center of the tube is surrounded by a carapace of pillow basalt. Line drawing from photographs.

contain latest Eocene foraminiferal faunas. The camptonitic extrusive sequence is approximately equivalent in age to the basalt flows of latest Eocene age that form Cascade Head and Cape Perpetua. The internal structure of the camptonitic extrusive sequence is complex; mapping along the poorly exposed northern part of the sequence (see Snavely, MacLeod, and Wagner, 1972a) suggests that the breccia and tuff were extruded along a west-trending fault whose scarp restricted the northern extent of the flows.

Continue west.

23.2 Top of camptonitic breccia and tuff sequence; small Miocene basalt dikes intrude the breccia in large road cut.

23.9 Large cut on right exposes tuff bed in Oligocene siltstone of Alsea.

24.1 Glauconitic sandstone interbed in siltstone of Alsea.

24.2 / 0 Junction U.S. 101. Turn left (south) across old bridge over Siletz River. Start new mileage.

1.0 Outcrop of fossiliferous glauconitic fine-grained sandstone and siltstone of the Yaquina Formation capped by Pleistocene terrace deposits.

1.5 to 4.5 Highway is constructed across Pleistocene marine terrace deposits that in places are overlain by ancient dunes.

5.1 Fogarty Creek State Park. Sandstone of the Astoria Formation and peperite dikes of Depoe Bay Basalt are well exposed along the coast.

5.4 Peperite dikes of Depoe Bay Basalt cutting Astoria Formation exposed on left side of road.

6.2 Turn west to Government Point State Park.

6.3 STOP 13. Cape Foulweather Basalt, Government Point State Park. The Cape Foulweather Basalt extends along the coast from Cape Foulweather to Government Point. At Cape Foulweather most of the extrusive tuff breccia is probably of subaerial origin. The water-laid, well-bedded lapilli tuff at Government Point (Figure 8) apparently formed part of a fringing marine apron around the main vent at Cape Foulweather (Snavely, MacLeod, and Wagner, 1973). Grading in many individual beds suggests that they were deposited by density currents; more massive units probably represent breccia transported by submarine landslides. Government Point is capped by sand and gravel of one of the lower marine Pleistocene terraces, but several nickpoints on the sea cliff indicate still lower sea level stands. On the north side of Boiler Bay just north of Government Point, peperite and basalt dikes of the Depoe Bay Basalt intrude sandstone and siltstone of the Astoria Formation. Cascade Head, the prominent headland 15 miles to the north, is underlain by upper Eocene subaerial basalt flows. Cape Lookout, visible on clear days about 35 miles north, is composed of a beautifully exposed sequence of pillow basalts and subaerial flows of the Depoe Bay Basalt.

Continue south on U.S. 101.

7.5 STOP 14. Depoe Bay Basalt, Depoe Bay. Isolated-pillow breccia of the Depoe Bay Basalt (Figure 9) forms the east margin of the outer bay on which U.S. 101 is constructed. Excellent exposures of this unit can be seen directly below the rock wall bordering the

Figure 8. Bedded lapilli tuff and breccia of the Cape Foulweather Basalt at Government Point (Stop 13). Tuff and breccia are formed of glossy or fine-grained basalt, and beds are graded and cross-bedded.

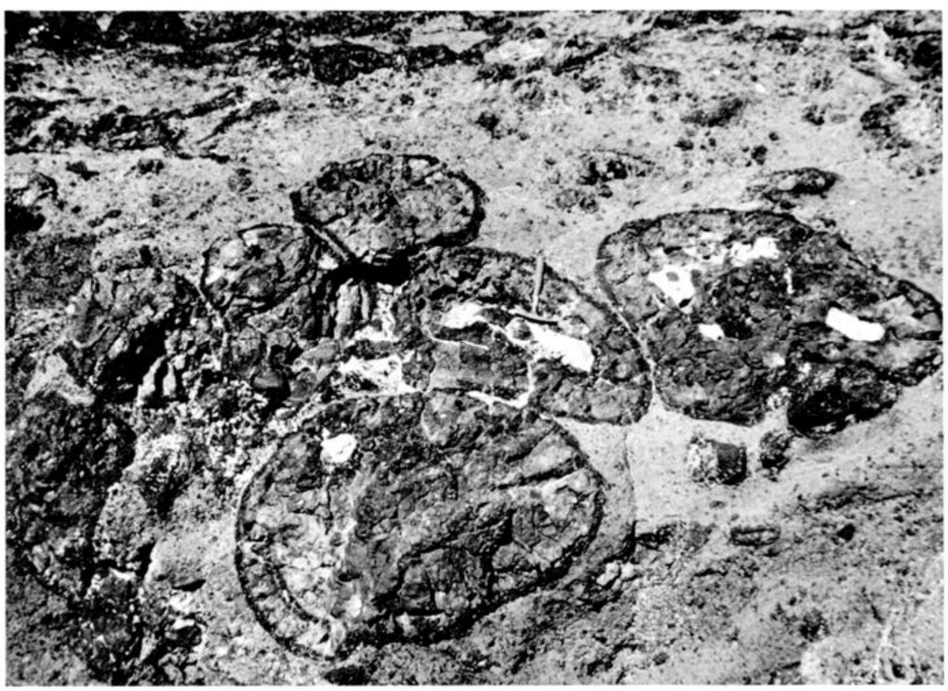

Figure 9. Isolated-pillow breccia of the Depoe Bay Basalt at Depoe Bay (Stop 14). Note the discontinuous chilled zone developed inward from outer chilled margin of the pillow in foreground and the sandstone-filled tension cracks and sandstone-filled core of the originally hollow pillow in center (under hammer).

west side of the highway. The Depoe Bay Basalt lies unconformably on the Astoria Formation, which is exposed in the inner bay, and is overlain by sandstone and siltstone of middle Miocene age that crop out along the south and north ends of the outer bay (Snavely, MacLeod, Wagner, 1973). The Cape Foulweather Basalt, which forms the projecting headlands on the outer Bay, unconformably overlies these sedimentary rocks. The breccia matrix of the isolated-pillow breccia of Depoe Bay Basalt is composed of glassy or very fine grained basalt that is palagonitized on weathered surfaces. Some breccia fragments are broken pillow rims. The pillows have ropy rims, and some have multiple chilled margins and drained-out cores. Finely comminuted basaltic glass or calcareous sand and silt fill some of the drained pillows. Clusters of snakelike pillows and very elongate pillows are exposed in several places within the isolated-pillow breccia and appear to have resulted from more rapid extrusion of lava into the marine environment. Small quarries 1/2 mile south of Depoe Bay reveal a thick, rudely jointed subaerial flow of Depoe Bay Basalt. Immediately north and south of these quarries, the lava apparently flowed into the Miocene sea and formed isolated-pillow breccia. Numerous dikes, sills, and irregular bodies of Depoe Bay Basalt intrude sandstone and siltstone of the middle Miocene Astoria Formation immediately east of Depoe Bay and were feeders to the extrusive basalt at Depoe Bay. The intrusive rocks include brickbat-jointed or brecciated basalt; the breccia resulted from intrusion of magma into water-saturated sediments. The Depoe Bay Basalt is relatively uniform in composition; typical analyses are listed in Table 4 (cols. 1 and 2). The basalt is characterized by a high content of SiO_2 and alkalies and is quartz-normative (Snavely, MacLeod, Wagner, 1973).

Continue south on U.S. 101.

9.4 View of Whale Cove on right (north). Outer jaws of cove are formed by Cape Foulweather Basalt; middle Miocene sandstone crops out in the cliffs that border the cove.

9.6 Rocky Point State Park. Thin flows and flow breccia of Cape Foulweather Basalt are cut by dikes and sills.

10.2 View of massive and rudely jointed tuff breccia of Cape Foulweather Basalt on left (east) side of road.

10.5 to 11.5 Highway passes through weathered breccia and tuff of the Cape Foulweather Basalt cut by numerous irregular intrusive bodies.

11.5 Pleistocene terrace deposits, about 550 feet above sea level, overlie Cape Foulweather Basalt.

12.0 Volcanic neck with radiating columnar joints.

Continue south 9 miles to starting point in Newport.

FIELD TRIP NO. 3

CENOZOIC STRATIGRAPHY OF NORTHWESTERN OREGON AND ADJACENT SOUTHWESTERN WASHINGTON

by

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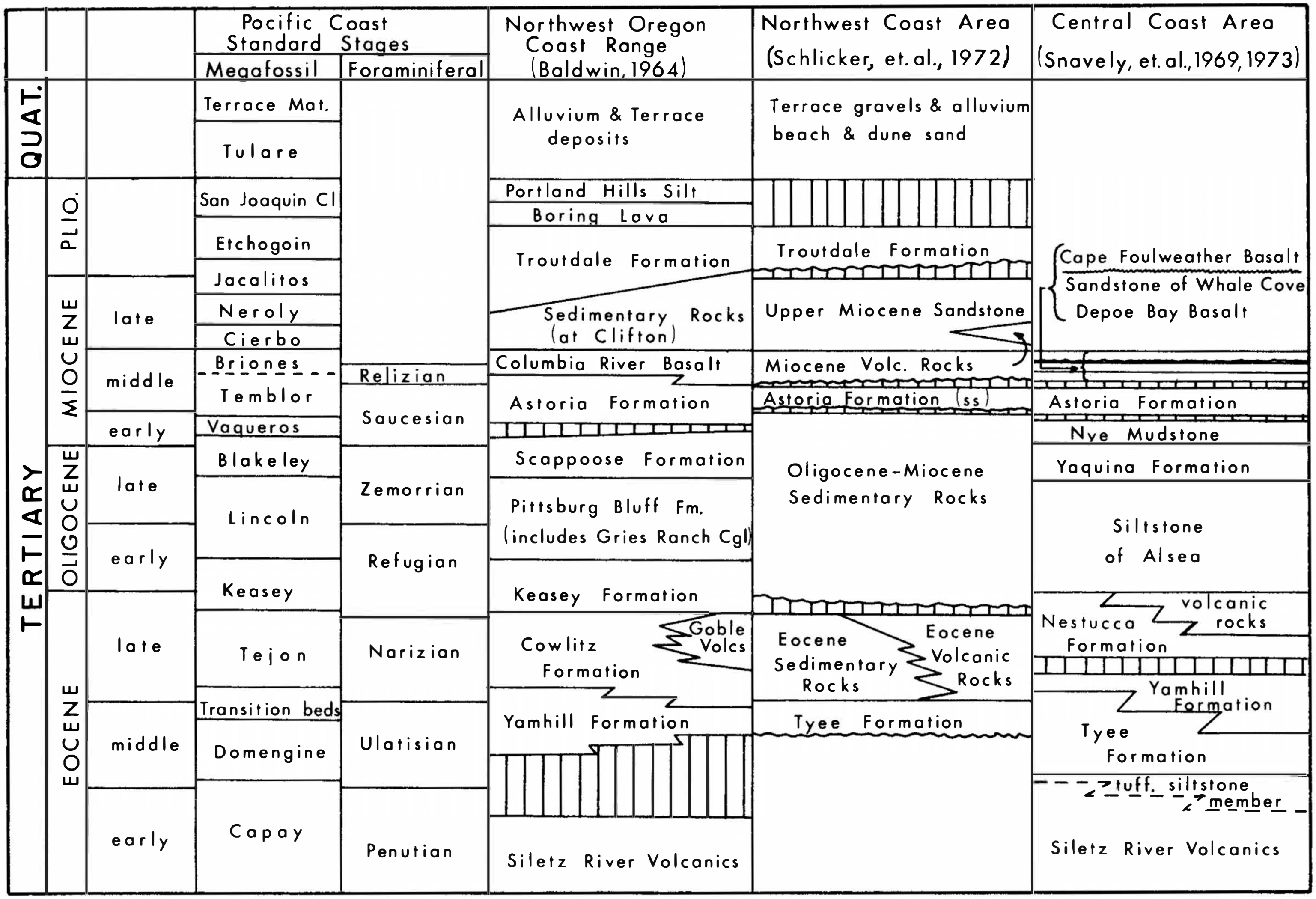
March 1973



STRATIGRAPHIC CHART FOR CENOZOIC, PACIFIC NORTHWEST COAST

CENOZOIC STRATIGRAPHY OF NORTHWESTERN OREGON AND ADJACENT SOUTHWESTERN WASHINGTON

Introduction

The Coast Range of northwestern Oregon and southwestern Washington contains an exceptional sequence of Tertiary volcanic and marine sedimentary rocks as well as Quaternary coastal deposits. This technical paper summarizes mainly published and some new information on the stratigraphy of northwestern Oregon and adjacent southwestern Washington. A field-trip road log of this area follows the paper. The formational units exposed in this area are correlative to Tertiary units near Newport in the central Oregon Coast Range (see accompanying stratigraphic charts). An excellent summary of the geologic history of western Oregon and Washington has been published by Snavely and Wagner (1963, 1964). Recent literature and maps dealing with the geology of the area have been published by Wells and Peck (1961), Livingston (1966), Baldwin (1964), Van Atta (1971b), Dodds (1969), Schlicker and others (1972), and Snavely, MacLeod, and Wagner (1973).

Acknowledgments

The authors express their thanks to Parke Snavely and Norm MacLeod, U.S. Geological Survey, for information on volcanic and intrusive rocks of the Coast Range in a pre-publication of their 1973 paper and to C. Kent Chamberlain, Ohio University, for identification and interpretation of trace fossils. Donald Parker, Oregon State University, obtained radiometric age dates of selected dikes and sills from the coastal area. Frank Cressy, Oregon State University, provided the geologic map of the Angora Peak-Neahkahnie Mountain area and detailed geologic information of the area from his thesis research.

Stratigraphy: Part I

The following descriptions of the Cowlitz, Keasey, Pittsburg Bluff, and Scappoose Formations are taken from Beaulieu (1971) "Geologic formations of western Oregon" with some modification by Van Atta.

Cowlitz Formation

In northwestern Oregon the Cowlitz Formation consists of as much as 1,000 feet of conglomerate, arkose, and siltstone interbedded in the upper part with basaltic flows and breccias of the Goble Volcanics member. The conglomerates are local, generally related to pillow basalts and breccias, and range in thickness from a few feet to as much as 200 feet. They are commonly fossiliferous. The arkose is generally unfossiliferous, except for plant debris. The Cowlitz Formation is believed to rest unconformably on late Eocene lavas and breccias, which are named the Tillamook Volcanic Series by Warren and others (1945), and is overlain by the Keasey Formation. The Cowlitz Formation is late Eocene in age and is correlative with the Tejon Formation of California, the Coaledo Formation of the southern Coast Range of Oregon, and, in part, with the Spencer and Nestucca Formations of the north central Coast Range of Oregon.

COMPOSITE STRATIGRAPHIC COLUMN OF FORMATIONS AND LITHOLOGIES OF TERTIARY SEDIMENTARY AND VOLCANIC ROCKS EXPOSED IN NORTHWESTERN OREGON AND ADJACENT SOUTHWESTERN WASHINGTON

Age	Formation and Thickness	Description
Holocene	0-300 feet	Floodplain alluvium and terraces of bedded basaltic gravels and/or light gray to light brownish-yellow silty clays along stream drainages of the Coast Range. Dune and beach sands, peat deposits, and organic-rich tidal flat muds and silts along coastal plain, spits, estuaries, and coastal lakes.
Pleisto-cene	Marine terraces 10-100 feet	Weathered gravels, cross-bedded sand, buried soils and horizons with abundant fossil logs, silt, and clays. Occur along coast in wave-cut cliffs and in protected coves.
Pliocene-Pleisto-cene	Portland Hills Silt 25-100 feet	Structureless light brown to buff silt. Mantles hills west of Portland; in part eolian and fluvial origin.
Pliocene	Boring Lava 0-800 feet	Blocky light gray diktytaxitic or vesicular olivine basalt flows and subordinate amounts of cinders and scoria. Present in Portland area.
		- - - - - - - - UNCONFORMITY - - - - - - - -
	Troutdale Fm. 50-900 feet	Poorly consolidated fluvial conglomerates and interbeds of friable sandstones and mudstones. Scattered well-rounded quartz, quartzite, and volcanic pebbles characterize the formation.
		- - - - - - - - UNCONFORMITY - - - - - - - -
Mid Miocene-early Pliocene (?)	Non-marine sedimentary rocks (at Clifton) 500+ feet	Massive, friable, arkosic and micaceous fluvial sandstone. Locally cross-bedded and contains channels and siltstone clasts. Some laminated micaceous and carbonaceous siltstone interbeds. Exposed along Columbia River at Clifton and in western part of Oregon Coast Range.
Middle Miocene	Columbia River Group (Yakima Basalt) 1400 feet	Dense, black to dark gray, aphanitic basalt flows characterized by well-developed columnar jointing; vesicular rubbly oxidized upper portions of flows. Contains several arkosic sandstone and conglomeratic interbeds along Columbia River. Up to 50 feet of ferruginous laterite is developed locally on top of Columbia River Basalt. The unit is exposed on east side of Coast Range and along Columbia River.
	Middle Miocene volcanics and intrusives 2000 feet	Coeval with Columbia River Basalt - locally derived basaltic breccias, pillow basalts, rare basalt flows, and associated sills, dikes, and pod-like basaltic intrusions (Depoe Bay type). A few dikes of younger Cape Foulweather Basalt. Volcanic rocks form highest peaks in western Coast Range and sills form headlands.

Composite Stratigraphic Column (continued)

Age	Formation and Thickness	Description
	Astoria Fm. 1000 to 1300 feet	In type area, 3 members: (1) an upper thick massive and cross-bedded arkosic and micaceous sandstone with few interbeds of mudstone; (2) a medial thick sequence of fossiliferous dark gray mudstones containing a few thin glauconitic sandstone beds; and (3) a lower 150-foot thick unit of thin-bedded laminated fine-grained sandstones alternating with beds of mudstone. Exposed along western part of Coast Range. Rhythmically bedded silty mudstone and graded sandstones at Ecola State Park. Beds commonly deformed in large-scale penecontemporaneous slump folds.
	Angora Peak sandstone member (informal) of Astoria Fm. 1000+ feet	In Cannon Beach area, thick sequence of indurated massive to cross-bedded coarse-grained arkosic sandstones, pumiceous conglomerates, carbonaceous siltstones, and local coal lenses that locally were deformed at the time of deposition.
Late Oligocene early Miocene	Mudstones of Oswald West Park 1500 feet	Well-bedded sequence of alternating mudstones and tuffaceous siltstones. Some graded and convolute bedded graywackes and tuffaceous sandstones. Mudstones and siltstones contain abundant burrow structures, minor clastic dikes, and pebbly mudstones. The beds are partly equivalent to the Scappoose in age.
Late Oligo-cene	Scappoose Fm. 1500 feet	Thick-bedded yellowish to buff micaceous and tuffaceous mudstone. Cross-bedded sandstones commonly contain carbonized wood and leaf imprints, scattered pebbles of quartzite and basalt. Base contains basalt cobble or mudstone pebble conglomerate. Exposed north of Mist and Vernonia in northeastern part of Oregon Coast Range.
Middle Oligo-cene	Pittsburg Bluff Fm. 850 feet	Thick massive to laminated beds of arkosic and glauconitic sandstone and siltstone in basal part; tuffaceous sandy siltstone and mudstone with local beds of basaltic conglomerates, cross-bedded channels, and coal lenses in upper part. Exposed east of Pittsburg and Vernonia in Coast Range.
Late Eocene-early Oligo-cene	Keasey Fm. 1800 feet	Three members: (1) an upper thin sequence of concretionary tuffaceous siltstone and mudstone beds; (2) a medial thick sequence of massive tuffaceous fossiliferous siltstone, and (3) a lower calcareous pebbly volcanic sandstone that interfingers with dark gray glauconitic tuffaceous mudstone. Exposed in eastern part of Oregon Coast Range, upper Nehalem River basin.
Late Eocene	Cowlitz Fm. 1000 feet	Arkosic sandstone, siltstone, tuffaceous mudstone, and locally minor basaltic conglomerate. Unit of basalt flows and coaly lenses in southern Washington. Sandstones contain plant debris. Exposed in eastern part of Coast Range in Oregon and Washington.
	Goble Volcanics 200-3000(?) feet	Basalt flows, pillow basalts, flow breccia, and interbedded sedimentary rocks. Interfingers with Cowlitz Formation. Exposed in northeastern part of Coast Range in Oregon and adjacent southwestern Washington.

Keasey Formation

The Keasey Formation in the upper Nehalem River basin is divided into three members (Warren and Norbisrath, 1946). The lower member consists of approximately 600 to 700 feet of thin beds of calcareous pebbly volcanic sandstone interfingering with thicker beds of dark gray, glauconitic tuffaceous mudstone. The middle member is about 1,800 feet thick in the vicinity of the Sunset tunnel (U.S. Highway 26) and consists of massive tuffaceous fossiliferous siltstone. The upper member is 200 to 300 feet thick and consists of concretionary tuffaceous siltstone and mudstone beds interfingering with thin pumiceous tuffaceous siltstone. The contact of the Keasey Formation with the underlying Cowlitz Formation in the upper Nehalem River basin is poorly understood. Conformity is suggested by some similarities in rock type, difficulty of placing the contact in the field, and the apparent concordance of individual outcrops. In the vicinity of Rocky Point, however, angular unconformity is suggested because of differences in strike up to 90° between the arkose of the Cowlitz Formation and the overlying Keasey Formation.

The Keasey Formation is latest Eocene to early Oligocene in age and is correlative with the Bastendorff Formation of the Coos Bay region and, in part, with the lower part of the "siltstone of Alsea" in the central Coastal Range.

Pittsburg Bluff Formation

The Pittsburg Bluff Formation consists of several hundred feet of massive to finely laminated arkose, glauconitic sandstone, siltstone, mudstone, and conglomerate. Arkosic sandstone and finely laminated siltstone is characteristic of the base of the formation, whereas thick massive beds of sandy mudstone are typical of the uppermost Pittsburg Bluff Formation. Locally, near the contact with the overlying Scappoose Formation, coarse-grained pebbly sandstone with abundant brown plant debris and/or basaltic conglomerate is found. Coal-bearing interbeds are also found in the upper part of the section.

The Pittsburg Bluff Formation seems to be conformable with the underlying Keasey Formation and with the overlying Scappoose Formation. It is middle Oligocene in age and correlates with the Eugene Formation, the Mehama Volcanics in the northwest Cascade Mountains of Oregon, the Oligocene tuffs of the Eugene area (included in the Fisher Formation), the upper Toledo Formation, and the upper part of the "siltstone of Alsea" of the Central Coast Range.

Scappoose Formation

The Scappoose Formation is made up of as much as 1,500 feet of fossiliferous, micaceous tuffaceous arkose and gray tuffaceous mudstone. The sandstone of the Scappoose Formation is quite similar to the arkose of the Cowlitz Formation. The mudstone facies is very much like the mudstones of the Keasey and the Pittsburg Bluff Formations. At the base, in contact with the Pittsburg Bluff Formation, basaltic cobble conglomerate or mudstone pebble conglomerate is present. Carbonized wood and other plant debris and scattered pebbles of basalt and quartzite occur in many outcrops. Interfingering relationships, variation in rock-type, and primary structures suggest that the Scappoose Formation is of deltaic origin. The Scappoose Formation rests with apparent disconformity upon the Pittsburg Bluff Formation and is overlain unconformably by basaltic flows of the Columbia River Group. Several hundred feet of relief was developed on the underlying Tertiary sedimentary formations before outpouring of the lavas of the Columbia River Group. Remnants of Columbia River Group basalt overlying with angular unconformity the Keasey and Pittsburg Bluff Formations on the Scofield surface suggest deformation of the older rocks prior to eruption of the basalts. The Scappoose Formation correlates with the Nye Mudstone and Yaquina Formation of the west-central Coast Range and contains a molluscan fauna referrable to the Blakeley Stage of late Oligocene to lowermost Miocene age.

Stratigraphy: Part II

Mudstone of Oswald West (informal)

On the coast, a thick sequence of interbedded silty mudstones and tuffaceous siltstones occurs in the Neahkahnie Mountain-Angora Peak area and is informally referred to in this paper as the mudstones of Oswald West. A 1,500-foot stratigraphic section occurs along Short Sand Beach in Oswald West State Park 30 miles south of Astoria. The sequence is overlain by the conglomerates and cross-bedded sandstones of the Angora Peak sandstone member (informal) of the Astoria Formation, and the base of the sequence is in contact with a basaltic sill. A variety of well-developed trace fossils is scattered through the mudstones and siltstones. A few thick graded graywacke beds contain mudstone "rip-ups". Other sedimentary features include load structures, convolute bedding, clastic dikes, and submarine mudflow deposits.

Mollusks collected from the mudstones by Warren and Norbisrath (1945) and abundant foraminifera from the lower part of the unit indicate a late Oligocene age. A sparse microfauna in the upper part of the unit suggests a Miocene age. The unit is, in part, equivalent in age to the Scappoose Formation in the northeastern part of the Oregon Coast Range. Sedimentary structures and microfossils indicate deposition of these silts, sands, and muds in a deep-water pelagic environment.

Astoria Formation

The Astoria Formation occurs in the western part of the Oregon Coast Range in a series of embayments from Newport to Astoria, the type area (Wells and Peck, 1961). The strata were originally studied at Astoria by Dana (1849), and the fossils collected there by Townsend were identified by Conrad (1848) in one of the first published papers on the Tertiary of the Pacific Coast.

Howe (1926) divided the Astoria Formation in the type area into three members: a lower sandstone approximately 150 feet thick, which is gradationally overlain by a middle shale member approximately 1,000 feet thick, and an upper sandstone. The poorly exposed lower sandstone member consists of massive to thin-bedded laminated fine-grained sandstones alternating with dark-gray sandy mudstones containing small calcareous concretions and abundant molluscan fossils. The thick shale member is composed of medium- to dark-olive-gray massive mudstone with a few thin interbeds of concretionary glauconitic sandstone. The mudstone contains calcareous and pyrite concretions (up to 6 inches in diameter). Several unfossiliferous massive to cross-bedded arkosic and micaceous sandstone beds (10 to 100 feet thick) form the upper sandstone member. The sandstones are coarse-grained and are interbedded with mudstone.

The stratigraphic boundaries of the Astoria with other formations are not defined in the type area. Lowry and Baldwin (1952) and Baldwin (1964) indicated that the upper sandstone member of Howe interfingers with basaltic breccias equivalent to the Columbia River Basalt east of Astoria.

The name Astoria Formation has been applied to many of the middle Miocene marine sedimentary rocks mapped in western Oregon and Washington. However, the rock-stratigraphic definition of the Astoria Formation varies in different mapped areas in the Pacific Northwest because correlation with the type locality has commonly been determined on a faunal basis and not on the basis of lithology or mapping into the type area (Moore, 1963).

Unfortunately, most of the original exposures of the Astoria in the type area are now covered with buildings or by sand dredged from the Columbia River. There is no well-exposed described type section of the Astoria in the type area to provide an adequate lithologic and stratigraphic basis for re-examination for definition and extension of the formation into other areas.

In addition, Dodds (1969) presented evidence of an unconformity near the type area between the upper sandstone and middle shale members of the Astoria Formation as defined by Howe (1926). He suggested restricting the name Astoria Formation to the lower sandstone and middle shale members of Howe and referred to the upper sandstone member as the post-Astoria sandstone. In practice, however, most sedimentary rocks mapped as Astoria Formation in other areas may be correlative with the upper sandstone member (Howe,1926) of the Astoria Formation (Beaulieu, 1971). The name Astoria Formation, with all its uncertainties, has now become deeply ingrained in the literature. Moreover, the precise location of Dodd's unconformity in the type area has yet to be determined. Possibly it passes beneath all of the Astoria section at Astoria. Moore (1963) and Dodds (1969) presented thorough discussions of the history of work on the type Astoria.

There is a definite need for the establishment and detailed description of a well-exposed, accessible type section of the Astoria Formation with defined upper and lower stratigraphic contacts. Furthermore, an intensive regional study is needed to define the stratigraphic, paleontologic, and lithologic relationships of the strata mapped as the Astoria Formation in Oregon and Washington with the type locality and with the newly defined type section.

In the Newport embayment, 100 miles south of Astoria, the stratigraphic relationships and lithologies of strata mapped as the Astoria Formation are more clearly defined (Vokes and others, 1949; Snavely and others, 1969). The 2,000-foot thick Astoria Formation unconformably overlies the early Miocene Nye Mudstone and late Oligocene Yaquina Formation and is unconformably overlain by the middle Miocene basalt of Depoe Bay. The formation consists of predominantly shallow marine arkosic and micaceous sandstones and carbonaceous siltstones.

Strata in the Cannon Beach area mapped as Astoria Formation by Wells and Peck (1961) are informally referred to in this paper as the Angora Peak sandstone of the Astoria Formation. Preliminary studies show that these strata are equivalent in age to the type Astoria. They consist of thick, massive to cross-bedded, arkosic, and tuffaceous sandstones. Subordinate amounts of pumiceous conglomerate, dark-gray mudstones, micaceous and carbonaceous burrowed siltstones, and a few thin discontinuous coal beds also occur. Abrupt facies changes are common in this sandstone member. More than 1,000 feet of section are present near Angora Peak (Frank Cressy, graduate student at Oregon State University oral communication, 1972).

In the precipitous sea cliffs at Oswald West State Park, the Angora Peak sandstone member overlies the late Oligocene (Zemorrian) to early Miocene (?) well-bedded tuffaceous siltstones and mudstones of Oswald West State Park and is unconformably (?) overlain by the middle Miocene basaltic breccia (equivalent to Columbia River Basalt) at Haystack Rock near the city of Cannon Beach.

Schlicker and others (1972), in remapping the northwestern Oregon coast area, restricted the use of the term Astoria Formation to this distinctive middle Miocene sandstone unit in an area 25 to 75 miles south of Astoria. They suggested, however, that these sandstones may be equivalent in age to the deeper-water facies of the type Astoria Formation at Astoria. They also accepted the possibility that the sandstone may unconformably overlie the lower sandstone and mudstone members of the Astoria Formation at the type locality.

The conglomerates in the Angora Peak sandstone member consist of abundant pumice, basalt, quartz, and agate pebbles probably derived from Miocene pyroclastic eruptive centers in the ancestral Cascades to the east and from older Eocene basaltic and sedimentary highlands in the Coast Range. Basaltic conglomerates containing sandstone boulders as large as 11 feet across occur locally. Trough and large-scale planar cross-bedding, scour-and-fill structures, channels, convoluted bedding, mud "rip-ups", flame and load structures, and marine sandstones are common locally. The orientation of cross-bedding shows a sediment dispersal pattern from east to west, northwest, and southwest. Areal reconnaissance suggests that the Angora Peak sandstone member interfingers with shallow marine sandstones to the south and deeper-water mudstones to the north. The probable environment of deposition is deltaic as suggested by lithologies, sedimentary structures, and lateral facies distribution.

Preliminary observations also indicate that a deep-water turbidite sandstone facies over 200 feet thick at Ecola State Park near Cannon Beach may be equivalent in age to the type Astoria. This sequence, mapped by Wells and Peck (1961) as the Astoria Formation, consists of a rhythmic alternation of well-bedded, micaceous, laminated fine-grained sandstones and silty mudstones of Saucesian and Relizian age. Sedimentary structures in the sandstone beds include the a, b, and c divisions of the Bouma sequence. Parallel laminations, micro cross-laminations, contorted stratification, graded bedding, mud clasts, load structures, and rare sole marks also occur.

The sandstones and conglomerates of the Angora Peak sandstone member along the sea cliffs at Hug Point State Park and the Astoria-age sequence at Ecola Park form large penecontemporaneous slump folds commonly associated with middle Miocene basaltic dikes and sills. Radiometric age dating indicates that these igneous rocks are only slightly younger than the sedimentary rocks they intrude. Donald Parker, Oregon State University, radiometrically dated a sample from a dike at Ecola State Park at 15.9 ± 0.4 m.y. (middle Miocene) and Turner (1970) determined an age of 14.0 ± 2.7 m.y. for basalts near Ecola Park. These intrusions contain blocks of contorted middle Miocene sedimentary rocks.

The contacts of the sills and dikes with the surrounding sedimentary rocks are locally altered and brecciated, and some are peperites, suggesting that the igneous intrusions displaced still plastic or semi-lithified water-saturated sediments, throwing them into huge folds and jumbled angular blocks of sediment in a sandstone matrix. Some soft sediment folding, not obviously associated with dikes, may have been produced by slumping on the front of a delta.

Age: The Astoria Formation as mapped in western Oregon is now generally considered middle Miocene in age, but recent published ages range from middle Oligocene to middle Miocene depending on the locale where the strata assigned to Astoria Formation were sampled. In the type locality, the foraminiferal assemblage is referrable to Kleinpell's (1938) upper Saucesian Stage of the middle Miocene (Cushman and others, 1947; Stewart, 1956). The lower sandstone and middle shale of Howe in the type area contain a distinctive molluscan fauna which is Temblor or middle Miocene in age (Moore, 1963).

In the Svensen area 9 miles east of Astoria, strata assigned to the Astoria Formation by Dodds (1963, 1969) contain middle Refugian (mid-Oligocene) to Saucesian (early Miocene) foraminiferal assemblages. The overlying post-Astoria sandstones (equivalent to Howe's upper sandstone member of the Astoria Formation) contain a megafossil assemblage collected and identified by Dodds which is most probably of middle Miocene age according to Addicott (in Snavely, MacLeod, and Wagner 1973).

The siltstones of the Astoria Formation in the Newport area contain abundant foraminifera indicative of a Saucesian age (Snavely and others, 1964, 1969) and a megafossil assemblage indicative of a Temblor or middle Miocene age (Vokes and others, 1949; Moore, 1963; Snavely and others, 1964, 1969). A middle Miocene megafossil fauna was described from exposures of sandstones of the Astoria Formation along the south side of Tillamook Bay (Moore, 1963), and Miocene foraminifera occur in the Angora Peak sandstone member near Angora Peak. Foraminifera of Saucesian (Schlicker and others, 1961) and Relizian (Snavely and others, 1973) age have been reported in the turbidite strata mapped as Astoria Formation by Wells and Peck (1961) at Ecola State Park near Cannon Beach.

Columbia River Group

Basalts of the Columbia River Group (referred to as Columbia River Basalt in this report) form the high hills and ridges from Portland to the northeastern part of the Oregon Coast Range and form steep cliffs along the lower Columbia River as far west as Cathlamet, Washington, and Westport, Oregon 25 miles east of Astoria. Fresh basalt flows are dense, dark gray to black and aphanitic to fine grained. Flows are characterized by well-developed columnar jointing and vesicular rubbly oxidized upper parts. The basalts are composed of plagioclase, augite, pigeonite, and opaque minerals set in a groundmass of brown glass and chlorophaeite. A few flows contain minor olivine.

The Columbia River Group in eastern Oregon consists of three formations: the Picture Gorge Basalt, the Yakima Basalt, and the Mascall Formation (Snavely and others, 1973). Waters (1961) subdivided the Yakima basalts into two petrographic types: the Yakima and the late-Yakima. The flows in northwestern Oregon and southwestern Washington (derived from the Columbia River plateau) are equivalent to the Yakima and late Yakima petrographic types (Snavely and others, 1973).

Individual flows range from 30 to 60 feet thick and are separated by several 5- to 20-foot-thick interbeds of arkosic sandstones and less commonly basaltic conglomerates along the lower Columbia River. A reddish ferruginous bauxite-laterite Miocene soil zone is developed locally on top of the Columbia River Basalt in Washington and Oregon. The Columbia River Basalt has been broadly warped into several large northwest-southeast trending anticlines and synclines in the eastern part of the Coast Range and in the Portland area. The total thickness of the Columbia River Basalt in the Kelso-Cathlamet area of Washington along the Columbia River is at least 1,400 feet (Livingston, 1966).

The Columbia River Group unconformably overlies the Oligocene Scappoose, Pittsburg Bluff, Keasey Formations, the late Eocene Goble Volcanics, and the Cowlitz Formation in the upper Nehalem River area. Van Atta (1971a) refers to this erosional unconformity as the Scofield surface. Locally, the Columbia River Basalt is unconformably overlain by the Troutdale Formation and Portland Hills Silt (Livingston, 1966; Warren and Norbisrath, 1946). In the northwestern part of the Oregon Coast Range, the basalts intertongue with the Astoria Formation (Baldwin, 1964) and are overlain by middle Miocene-early Pliocene non-marine sedimentary rocks (Wells and Peck, 1961). Some flows grade westward into submarine pillow lavas and palagonite breccia in the Big Creek area 14 miles east of Astoria, probably indicating where the flows poured into a marine embayment (Snavely and others, 1973; Baldwin, 1964).

The Yakima and late-Yakima petrographic types of basalt in northwestern Oregon and southwestern Washington are middle Miocene in age.

Miocene volcanic rocks and intrusions

The middle Miocene volcanic rocks along the coast of northwestern Oregon consist of more than 1,500 feet of tholeiitic pillow basalts, basaltic breccia, and basalt flows which overlie the Astoria Formation. These basaltic rocks are chemically indistinguishable from and are coeval with the plateau-derived Yakima and late-Yakima basalts of the Columbia River Group (Snavely and others, 1973).

The highest topographic features in the northwestern Oregon Coast Range (Wickiup Mountain, Onion Peak, Saddle Mountain, Sugarloaf Mountain, and Angora Peak) are composed of predominantly massive resistant basaltic breccia. These topographic highs probably represent centers of igneous activity as swarms of feeder dikes and sills cut the breccias. The basaltic rocks range from flows with closely packed pillows to isolated pillows in a basaltic breccia. The breccias are composed of poorly sorted angular fragments of basaltic glass (sideromelane and tachylite) that commonly weathers to yellowish-brown palagonite. Larger fragments are composed of aphanitic basalt, some of which contains zeolite and calcite-filled amygdules. Large blocks of contorted mudstone and siltstone are incorporated into some of the breccias. These breccias and isolated pillow breccias probably were formed as hot molten masses of basalt extruded on the sea floor. The igneous material shattered as a result of rapid quenching by sea water.

Snavely and others, (1973) subdivided the middle Miocene volcanic and intrusive rocks along the Oregon and Washington coast into three major units based on petrochemistry, mineralogy, and relative stratigraphic positions. From oldest to youngest they are: Depoe Bay Basalt, Cape Foulweather Basalt of the Newport area, and basalt of Pack Sack Lookout (informal name) of southwestern Washington.

The non-porphyritic Depoe Bay Basalt, which has a high-silica content, forms the bulk of the dikes, sills, pillow basalts, and flow breccias of the northwest Oregon coastal region (Snavely and others, 1973). The Cape Foulweather Basalt is characterized by scattered yellowish phenocrysts of labradorite. It occurs in minor amounts as dikes cutting Depoe Bay Basalt sills at Ecola State Park and as an inclined dike sheet at Youngs River Falls. The basalt of Pack Sack Lookout contains large phenocrysts of labradorite with inclusions of pyroxene and glass in addition to augite and olivine phenocrysts. This unit comprises a few flows that unconformably overlie Yakima Basalt in the Kelso-Cathlamet area of Washington. The Depoe Bay Basalt is chemically equivalent to the Yakima Basalt of the Columbia River Group, and the Cape Foulweather Basalt is chemically equivalent to the late-Yakima Basalt (Snavely and others, 1973).

Numerous basaltic sills, dikes, and pod-like intrusions associated with the eruptive development of the Miocene volcanic rocks penetrate the underlying Astoria Formation and late Oligocene mudstones. Some of the sills are thick (up to 1,000 feet), massive, and form resistant headlands such as Tillamook Head, Neahkahnie Mountain, or Cape Falcon along the coast or ridges such as Coxcomb Hill in the city of Astoria. These sills generally dip gently southeastward and are commonly in fault contact with surrounding Oligocene and Miocene mudstones and sandstones. The upper surface of many of the large sills is irregular and contains dike-like apophyses with incorporated blocks of the surrounding deformed Oligocene-Miocene sedimentary rocks.

The massive sills are fine-grained basalt to gabbro and show little compositional differentiation (Snavely and others, 1973). Some dikes are composed of altered brecciated basalt and of peperite that contains brecciated sedimentary blocks. The breccia dikes probably formed from steam explosion and rapid quenching during extrusion into water-saturated sediments (Snavely and others, 1973). Dikes commonly become irregular, bifurcate, flay out in all directions, and become increasingly brecciated near the contact of the Astoria sedimentary rocks and the overlying extrusive breccias, suggesting intrusion close to the top of the sedimentary pile. The Depoe Bay Basalt and Cape Foulweather Basalt are middle Miocene (14 to 16 m.y.) in age and the basalt of Pack Sack Lookout is tentatively late Miocene based on potassium-argon dating and stratigraphic relationships.

Middle Miocene to Early Pliocene (?) non-marine sedimentary rocks (at Clifton)

The non-marine sedimentary rocks consist of approximately 500 feet of massive to cross-bedded, buff, commonly iron-stained, friable, arkosic sandstone overlain by carbonaceous sandstone and silty mudstone. The unit conformably overlies and interfingers with the upper part of the Columbia River Basalt. The arkosic sandstone is medium- to very coarse-grained, poorly sorted, and commonly micaceous. Interbeds 10 to 20 feet thick of laminated carbonaceous siltstones and very fine-grained sandstones are also present. The unit is semi-consolidated and forms sandy gentle slopes. The non-marine character of the sandstone is suggested by the occurrence of sandstone channels, laminated carbonaceous siltstone "rip-ups" and slump blocks. The mapped distribution of the unit (non-marine Pliocene sedimentary rocks of Wells and Peck, 1961) is restricted to a 45-square-mile area east of Astoria, Oregon, near Clifton, Brownsmead, and Gnat Creek Forest Park along the Columbia River and south of Astoria between Youngs River and the Lewis and Clark River. The unit is also referred to, in part, as the upper Astoria sandstone and is unconformably overlain by the Troutdale gravels (Lowry and Baldwin, 1952; Baldwin, 1964). Snavely and Wagner (1964) suggested that this non-marine unit is part of the deposits of the ancestral Columbia River system in the downwarped area of the lower reaches of the Columbia River.

No fossils have been described in these non-marine sandstones, however, burrows have been observed locally. The stratigraphic relationships suggest an age between middle Miocene and early Pliocene. It is difficult to differentiate these strata from the lithologically similar upper sandstone member of the Astoria Formation of Howe (1926) (post-Astoria of Dodds) in the Astoria area where there is no intervening Columbia River Basalt. Schlicker and others (1972) chose to combine the two units as one and mapped them as the upper Miocene sandstone in their recent reconnaissance mapping of the Astoria area.

Troutdale Formation

The Troutdale Formation is composed of semi-consolidated conglomeratic beds east of the Portland area near the town of Troutdale. Gravels and conglomerate correlated with the Troutdale Formation occur in restricted outcrops along the lower Columbia River in the Longview-Cathlamet area of Washington (Livingston, 1966) and in the Clatskanie and Astoria areas of Oregon (Schlicker and others, 1972).

The formation consists of poorly sorted well-rounded pebbles and boulders in a light-buff silty clay matrix. Scattered quartz, quartzite, and volcanic pebbles characterize the formation. The unit contains lenses of friable sandstone and mudstone within the gravels. The Troutdale is at least 50 feet thick at Astoria (Schlicker and others, 1972) and 900 feet thick in the Longview area (Livingston, 1966).

The gravels unconformably overlie the Astoria Formation at Astoria, the Eocene Goble Volcanics in the Longview area, and the Miocene Columbia River Basalt at Clatskanie, Oregon. The unit is overlain by the basaltic Boring Lava and by the Portland Hills Silt in the vicinity of Portland.

The well-rounded cobbles and lens-shape of the gravel deposits indicate a fluvial origin for this formation probably associated with the ancestral Columbia River system. The occurrence of the Troutdale Formation capping Coxcomb Hill in the city of Astoria indicates at least 250 feet of uplift since deposition of the gravel (Schlicker and others, 1972). The composition of the pebbles suggests derivation from a quartzite and metamorphic, acidic volcanic terrain in northwestern Washington or eastern Oregon and Idaho as well as from the basaltic andesites of the Cascades and the basalts of the Coast Range.

Age: Leaves examined by Chaney (1944) and by Sanborn (in Wilkinson and others, 1946) in the type area of the Troutdale indicate an early Pliocene age. Fossil leaves recovered from the Troutdale as restricted by Trimble (1963) also are indicative of an early Pliocene age.

Boring Lava

The Boring Lava forms and caps many of the topographic highs in the Portland area. The unit was named and mapped in the Portland area by Treasher (1942). The formation consists of light-gray to dark-gray diktytaxitic olivine basalt flows and minor amounts of cinders and breccias. The lavas characteristically are less dense than the Columbia River Basalt and contain zeolite- and opal-filled vesicles. Columnar jointing is poorly developed in the Boring Lava unlike the Columbia River Basalt.

The Boring Lava appears as large blocks in exposure. Mount Sylvania, the site of Portland Community College south of Portland, is composed of a small basalt shield volcano of Boring Lava (Burnam, 1972, personal communication).

Age and contacts: Most of the unit is considered to be middle to late Pliocene although the lower part may be early Pliocene. The unit disconformably overlies the early Pliocene Troutdale Formation. It is overlain and is, in part, interbedded with the Portland Hills Silt (Baldwin, 1964).

Portland Hills Silt

The Portland Hills Silt ranges from 25 to 100 feet in thickness and consists of a structureless light-brown to buff silt. The silt has been found in the Portland area and on the Tualatin Hills at elevations of 1,200 feet and in the lowland bordering the Columbia River at Vancouver, Washington, at an altitude of 300 feet. In the Kelso, Washington, area a 25 to 40-foot loess deposit on top of the Columbia River Basalt is correlative to the Portland Hills Silt (Livingston, 1966).

This silt was named and described by Lowry and Baldwin (1952). The silt is composed of quartz, muscovite, biotite, feldspar, augite, garnet, glass, spicules, diatoms, and the clay minerals kaolinite and illite and is lithologically similar to the Palouse soil of eastern Washington (Beaulieu, 1971). The Portland Hills Silt disconformably overlies the Columbia River Basalt, Troutdale Formation, and Boring Lava (with which it may be interbedded in part).

The Portland Hills Silt is post-Troutdale, middle Pliocene age, based on dating a fossil tooth (Baldwin, 1964). Yet early Pleistocene age is indicated by its stratigraphic position above the early Pleistocene Springwater Formation (Trimble, 1963).

The Portland Hills Silt probably was deposited in fluvial and eolian environments. Baldwin (1964) reported scattered well-rounded quartzite pebbles present in the silt suggesting a water-laid origin in part. The fine-grained, uniform character of the silts in other areas suggest they are loessal deposits derived from the Columbia River floodplain (Trimble, 1963; Livingston, 1966; Beaulieu, 1971). Rigorous analysis of the Portland Hills Silt is long overdue.

Pleistocene and recent unconsolidated deposits

Uplifted Pleistocene marine terraces occur from 10 to 100 feet above sea level along the coast. Deposits on the wave-cut terraces consist of weathered gravel, abundant logs, cross-bedded sand, buried soils, and silts and clays. Stream alluvium composed predominantly of bedded, poorly sorted reddish basalt gravels or light-gray to buff silty clays ranges from 0 to 15 feet thick although thicknesses up to 300 feet have been recorded locally (Schlicker and others, 1972). Older alluvium deposits occur in river terraces up to 50 feet above present flood plain levels along the lower reaches of larger streams.

Dune and beach sand and beach gravels occur in protected coves between headlands and along coastal plains. Clatsop Spit and the Clatsop sand plains form a 17-mile-long arcuate coastline from the mouth of the Columbia River to Seaside, Oregon, and is characterized by several parallel north-south beach ridges with intervening peat swamps and elongate lakes. Coastal plain sand is 100 to 150 feet thick.

The Clatsop sand plains are post-glacial in age and have formed from the distribution of sand brought to the sea by the Columbia River (Schlicker and others, 1972). The maintenance of the shape and continued seaward growth of the sand plains over the shallow shelf is produced by the movement of sand in response to a dynamic interplay between the northward flowing winter currents and the southward flowing summer currents (Cooper, 1958). The beach ridges range from 25 to 70 feet high and contain large-scale planar cross-bedding. The beach sands are compositionally quartzose and feldspathic but locally are dark due to heavy mineral concentrations. A large spit with northeasterly trending parabolic dunes projects southward into the mouth of the Nehalem River south of Neahkahnie Mountain.

Tidal flat deposits, composed of massive organic-rich silts, muds, and minor sand layers, and peat deposits are located in protected bays and estuaries and along the banks of the Columbia River. Wells have penetrated as much as 200 feet of tidal flat sediments (Schlicker and others, 1972).

Structure

Structurally, the northern Coast Range of Oregon is relatively simple. Many workers in the past have referred to the Coast Range as a north-plunging anticlinorium because of the general attitudes of rocks on the west, north, and east flanks of the Siletz River Volcanics which form the core in the central and north-central part of the range. Close examination of attitudes reveals, however, that there are local reversals in dip which suggest that aithough there is a general anticlinal upwarping, it would be difficult to trace out anticlines and synclines within the overall structure, in accord with J.D. Dana's (1873) original intent of the term "anticlinorium". The structural trend of faults and the few folds which can be delineated is generally northwest-southeast.

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APPENDIX A. SCHEDULE OF FERRY CROSSINGS

Wahkiakum Ferry - Puget Island to Westport, Oregon

Leaves Puget Island	Leaves Westport
7:15 A.M.	7:30 A.M.
7:45 A.M.	8:00 A.M.
8:15 A.M.	8:30 A.M.
8:45 A.M.	9:00 A.M.
9:45 A.M.	10:00 A.M.
10:45 A.M.	11:00 A.M.
11:45 A.M.	12:00 Noon
12:45 P.M.	1:00 P.M.
1:45 P.M.	2:00 P.M.
2:45 P.M.	3:00 P.M.
3:15 P.M.	3:30 P.M.
3:45 P.M.	4:00 P.M.
4:15 P.M.	4:30 P.M.
4:45 P.M.	5:00 P.M.
5:15 P.M.	5:30 P.M.
11:15 P.M.	12:15 A.M.

APPENDIX B. MEGAFOSSIL CHECK LIST

COWLITZ FORMATION

Cowlitz Formation (after Warren and Norbisrath, 1946):

Columbia County Quarry ("Rocky Point Quarry"), STOP 3

Glycymesis cf. *G. eocenica* (Weaver)

Barbatia cowlitzensis (Weaver and Palmer)

Barbatia suzzaloi (Weaver and Palmer)

Ostrea cf. *O. griesensis* Effinger

Podoesmus n. sp.

Mytilus n. sp. A

Mytilus n. sp. B

Volsella cowlitzensis (Weaver and Palmer)

Pitar cf. *P. escenica* (Weaver and Palmer)

Acmaca n. sp. A

Acmaca n. sp. B

Caliptraea diegoana (Conrad)

Terebratalia sp.

Deacon (1954, p. 63) gives the following additional megafossils found at the Columbia County Quarry:

Nuculanids

Ficopsis sp.

Septifer sp.

Acmaea persona Exchscholtz

Rhynochonella washingtonia Weaver

Hexacorals

Fish teeth

Unidentifiable vertebrate bone fragments

KEASEY FORMATION

Keasey Formation (after Warren and others, 1945): Sunset Tunnel - Empire Lite Rock Quarry, STOP 2

- Nucula n. sp.
- Acila nehalemensis Hanna
- Nuculana n. sp.
- Yoldia chehalisensis (Arn.)
- Tindaris ? n. sp.
- Delectopecten n. sp.
- Crenella porterensis W.
- Thracia n. sp.
- Nemocardium weaveri (Arnold and Martin)
- Macoma n. sp.
- Epitonium keaseyensis Durham
- Natica cf. N. weaveri Tegland
- Polinices n. sp.
- Sinum cf. S. obliquum (Gabb)
- Turritella n. sp.
- Bruclarkia n. sp.
- Mitra n. sp.
- Cancellaria n. sp. A
- Cancellaria n. sp. B
- Cancellaria n. sp. C
- Conus n. sp. B
- Exilia lincolnensis Weaver
- Spirotropis n. sp. A
- "Gemmula" bentsonae Durham
- Nekewis aff. N. washingtoniana (W)
- Nekewis n. sp.
- Knefastia aff. K. washingtoniana (W)
- Scaphander stewarti Durham
- Eumorphoscorystes naselensis Rath

KEASEY FORMATION

Mist crinoid locality: Moore and Vokes (1953) report the following:

- Isocrinus oregonensis Moore and Vokes n. sp.
- Isocrinus nehalemensis Moore and Vokes n. sp.
- Solemya (Achavax willapensis Weaver)
- Ennucula n. sp.
- Acila (Truncacila) nehalemensis Hanna
- Nuculana washingtonensis (Weaver) n. subsp.
- Yoldia (Portlandella) chehalisensis (Arnold)
- Minormalletia n. sp.
- Propeamussium n. sp.
- Delectopecten n. sp.
- Tellina n. sp.
- Polinices n. sp.
- Fulgurofusus n. sp.
- "Cancellaria" n. sp.
- Exilia lincolnensis Weaver
- Scaphander stewarti Durham
- Flabellum hertleini Durham

Mist crinoid locality: Bruce Welton, Portland State Univ. undergraduate student, has identified the following lower Oligocene sharks from teeth found at this locality:

- Pristoiphorus sp.
- Squatina sp.
- Squalus
- Centrophorus sp.
- Notorhynchus sp.
- Odontaspis sp.

PITTSBURG BLUFF FORMATION

Pittsburg Bluff Formation (after Warren and others, 1945) STOP 4

Acila shumardi (Dall)

Nuculana washingtonerisis (W.)

Yoldia aff. Y. tenuissima Clark

Limposis, ?, n. sp.

Thracia condoni Dall

Taras goodspeedi Durham

Nemocardium aff. N. lorenzanum (Arn.)

Macrocallista pittsburgensis (Dall)

Tellina pittsburgensis Clark

Solen townsendensis Clark

Spisula pittsburgensis Clark

Spisula packardi Dickenson

Panope snohomishensis Clark

Ervillia oregonensis Dall

Polinices washingtonensis (Weaver)

Polinices (Neverita) n. sp.

Eosiphonalia oregonensis (Dall)

Bruclarkia columbiana (Anderson and Martin)

Molopophorous gabbi Dall

Perse pittsburgensis Durham

Priscofusus cf. chehalisensis (Weaver)

Scaphander stewarti Durham

SCAPPOOSE FORMATION

Scappoose Formation (after Warren and Norbisrath, 1946)

Acila muta (Clark)

Acila aff. gettysburgensis (Reagen)

Nuculana sp.

Yoldia chehalisensis (Arnold)

Yoldia aff. oregana (Shumard)

Anadara cf. A. montereyana (Osmont)

Mytilus cf. M. matthewsoni Gabb

Thracia aff. trapezoides Conrad

Veneracardia cf. V. hannai Tegland

Taras parilis (Conrad)

Clinocardium scappoosensis (Clark)

Nemocardium lorezanum (Arnold)

Macrocallista weaveri Clark

Pitar arnoldi etheringtoni (Tegland)

Tellina oregonensis Conrad

Macoma twinensis Clark

Spisula albaria scappoosensis Clark

Spisula ramonensis attenuatta Clark

Panope ramonensis Clark

Bruclarkia acuminata (Anderson and Martin)

Perse aff. lincolnensis (Weaver)

ROAD LOG

by

Alan R. Niem, Robert Van Atta, Vaughn Livingston, and Weldon W. Rau

The first day of the field trip (Figure 1) is concerned with the upper Eocene to Miocene sedimentary and volcanic rocks of the eastern part of the Coast Range in northwestern Oregon and southwestern Washington. The route begins in Portland, Oregon, travels on paved roads for all but 1.8 miles of the trip, and includes a toll ferry crossing of the Columbia River from Puget Island (Cathlamet, Washington) to Westport, Oregon. A current (1972) schedule of ferry crossings is included in the appendix. The first day of the trip terminates in Astoria, Oregon.

The second day of the field trip (Figure 1) examines late Oligocene and Miocene sedimentary, volcanic, and intrusive rocks in the western part of the Oregon Coast Range and in exposures along the coast. In addition, Quaternary beach and spit deposits are observed. The route begins in Astoria, Oregon, and terminates in Portland.

The reader is referred to the technical paper which precedesthe road log for a description of formations and pertinent geologic information.

FIRST DAY

MILEAGE

Take U.S. Highway 26 (Clay Street) westward from downtown Portland toward Seaside.

0.0 Begin mileage at Vista Ridge Tunnel. Tunnel passes through flows of Yakima Basalt of the Columbia River Group. A series of at least six flows are upfolded into the Portland Hills Anticline. Dips on the northeast side of the anticline are generally less than 15 degrees, but across the Willamette River, no more than 4 miles from the foot of the Portland Hills, the top of the Columbia River Group lies at 1,000 feet below sea level, beneath 700 feet of gravel, conglomerates, and mudstones. Also, on the northeast flank of the Portland Hills Anticline edges of basaltic flows are truncated, resulting in faceted spurs and very steep slopes. These stratigraphic and topographic evidences (along with gravimetric and seismic evidences) point to the existence of a major fault.

0.1

0.1 Outcrops of Columbia River Group basalt in road cuts to right. What appears as soil is the Portland Hills Silt, which is unevenly distributed especially in topographic lows across the crest of the Portland Hills Anticline. Its thickness varies from 5 to 70 feet. The Portland Hills Silt is apparently unstratified, but in places a few pebbles are found. Although Lowry and Baldwin (1952) and other workers considered the Portland Hills Silt to be water-laid and of Pliocene age (predating the folding of the Portland Hills), Trimble (1963) considers the Portland Hills Silt to be loessal and of late Pleistocene age. Work remains to be done to establish with certainty the origin and age of the silt. Possibly a number of lithologically similar silt units of differing ages and environments of deposition crop out throughout the northernmost Willamette Valley and lower Columbia River Valley.

0.6

0.7 At 3 o'clock, notice in the road cut the baked contact between intracanyon basalt flow and underlying pyroclastics of the Plio-Pleistocene Boring Lava. At least three volcanic vents and cones cut through the Columbia River Group along the crest and southwest flank of the Portland Hills Anticline.

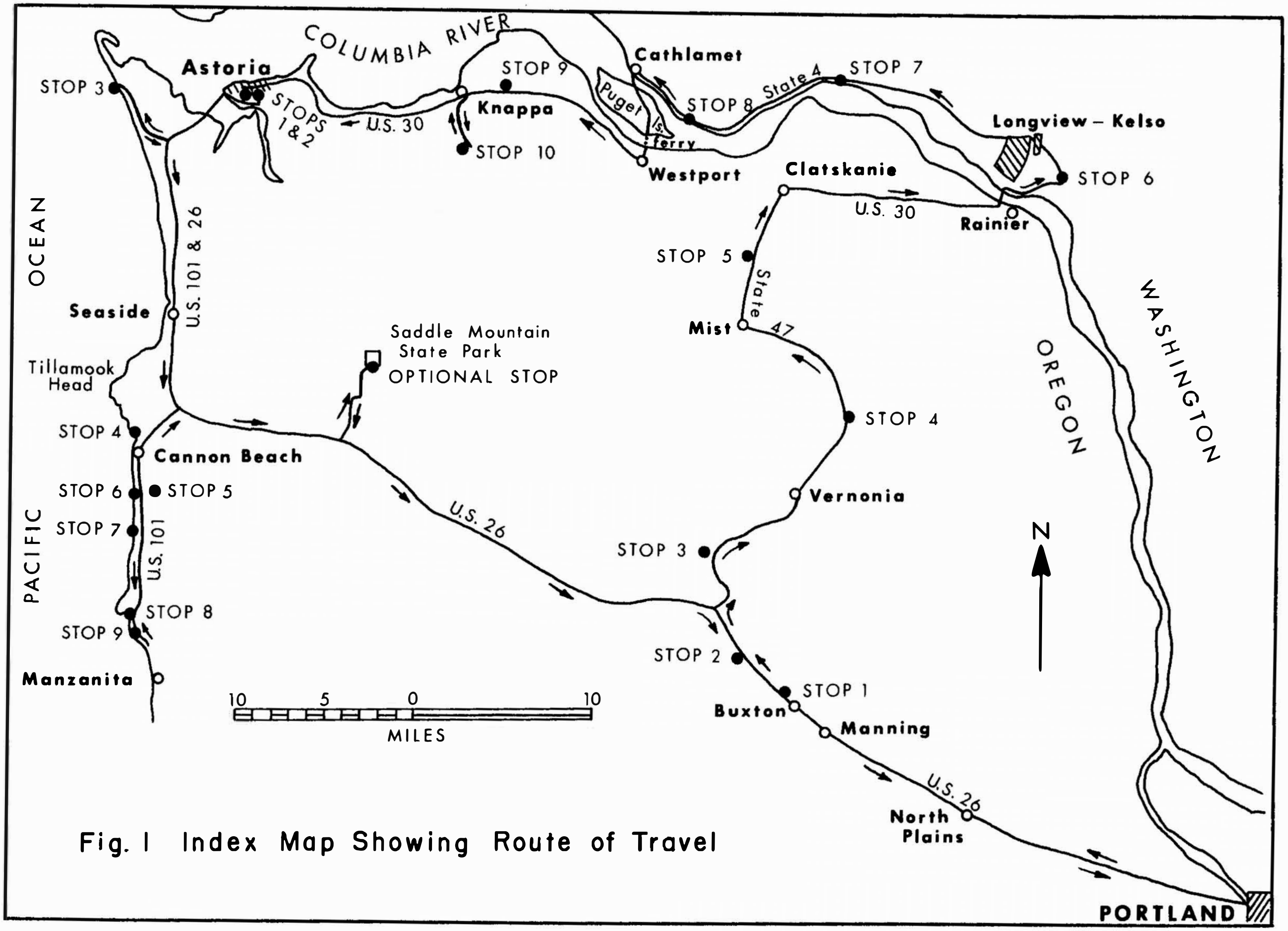


Fig. 1 Index Map Showing Route of Travel

0.6

1.3 At 3 o'clock, note exit to Portland Zoo and Oregon Museum of Science and Industry. Here up to 70 feet of Portland Hills Silt overlies the Yakima Basalt. During widening of the highway in 1959, removal of the toe of the northern slope reactivated an older landslide. Extensive fractures and movements of several feet in some places have endangered the buildings of OMSI and the Portland Zoological Gardens. Movements during the spring rainy season have averaged about five to six inches per year. Recently a deep channel was dug at the toe of the slide and was back-filled with basalt. During the past spring (1972) the slide appeared to be stabilized, despite exceptionally heavy rains.

1.2

2.5 Underpass at Sylvan Road; crest of Portland Hills Anticline.

0.5

3.0 At 9 o'clock, notice Mount Sylvania, a Boring Lava shield volcano, on the distant skyline. Diktytaxitic basaltic andesite flows from this vent underlie most of the topography on the south skyline.

0.4

3.4 Road cuts on either side with outcrops of Boring Lava. This is probably from a vent immediately to the north, Elk Point.

0.9

4.3 Road cuts in westernmost exposures of Boring Lava. These basaltic andesite flows mantle much of the western limb of the Portland Hills Anticline. The land surface to the north and south of the highway is generally a dip slope.

0.2

4.5 Junction, Oregon 217, keep straight on U.S. 26. At 3 o'clock is one of the plants of Tektronix, of Beaverton, Oregon, world-wide distributor of oscilloscopes and other electronic instruments.

0.6

5.1 Upper terrace level. Several terrace levels are present on the Plio-Pleistocene fill of the structural Tualatin Basin which you are now entering. Terraces possibly were formed during Pleistocene eustatic changes in sea level which may have created a sound in this region and in the Willamette Valley to the south.

3.7

8.8 To the right, on the far skyline, notice the crest of the Portland Hills Anticline. This is one of a series of NW-SE trending broad, gently plunging folds which underlie the region from the eastern edge of the Coast Range to The Dalles on the Columbia River. They are capped with laterite and ferruginous bauxite beneath silt.

1.5

10.3 You are now traveling over Plio-Pleistocene silts and sands which fill this structural basin in the Yakima Basalt. Some of the sediment may be equivalent to the Sandy River Mudstone. Well logs in this region show no gravels characteristic of those of the Troutdale Formation.

5.0

15.3 Historical marker. "Joseph L. Meek. This marks the land claim of Joseph L. Meek, famed and unlettered 'mountain man' who arrived in 1840 after driving from Fort Hall to Walla Walla in the first wagon on that part of the Oregon Trail. He was a founder of the provisional government; served as the first marshall and the first census taker. He carried the word of the Whitman massacre to Washington, D. C., where President Polk, whose wife was Meek's cousin, received him. Named marshall under the new territorial government, he accompanied Governor Lane to Oregon. His final Indian fighting was as a soldier in the Yakima war, 1855-56. He died here in 1875. A neighbor called him, 'very popular and as brave as Julius Caesar.'"

4.6

19.9 East Fork Dairy Creek. At 3 o'clock, see the comparatively wide flood plain of the creek built on the basin fill over which you are traveling.

3.2

23.1 Road cuts for next 0.3 mile in weathered Columbia River basalt. Dips here are to the northeast; this is the western edge of the Tualatin structural basin.

1.5

24.6 On left, road cut in muddy sandstone of the Scappoose Formation, overlain by weathered basalt. Flows of the Columbia River Group buried the early Miocene topography in this region.

0.1

24.7 On the left, cuts for the next 0.3 mile show pale yellowish sandstone of the Scappoose Formation (Oligo-Miocene) overlain by spheroidally weathered basalt. Some white "boulders" of leached weathered basalt can be seen in the upper part of the cuts.

0.3

25.0 On right, highest hills are capped by basalt flows overlying the Scappoose Formation.

0.6

25.6 On left, cut in hillside exposes the Scappoose Formation and overlying weathered Columbia River Basalt. The Scappoose Formation reaches its maximum thickness of approximately 1,500 feet in this region. It consists principally of finely cross-laminated, silty arkose with less than 5 percent clay matrix, interbedded with subordinate highly carbonaceous mudstone. Locally conglomerate is found in the basal Scappoose Formation, resting conformably on muddy sandstone and carbonaceous mudstone of the Pittsburg Bluff Formation. In the arkose, potash feldspar is nearly as abundant as plagioclase. Andesitic rock fragments, vitrophyre, and a little volcanic glass make up most of the balance of the framework grains. In the mudstone, pumice and pebbles of basalt and andesite are common. In places large amounts of carbonized wood are present in the mudstones. The Scappoose sediments contain abundant molluscan fossils.

0.8

26.4 Manning. Junction with Hayward and Pihl roads. Keep straight on U. S. 26.

2.7

29.1 STOP 1-1: Pull out on left in turnout. Road cuts here are in tuffaceous, micaceous sandy mudstone of the Pittsburg Bluff Formation (Oligocene) (see geologic map Figure 2). Volcanic glass may constitute up to 50 percent of some of the 6- to 8-foot-thick mudstone beds here. Mollusks and carbonized wood are fairly common. The yellowish mottling caused by weathering is very typical of the muddy tuffaceous sediments of the Pittsburg Bluff Formation throughout the upper Nehalem River Basin. Six-inch light-gray tuffaceous claystone layers are interbedded with the sandstone. Coarser sand is impressed into the claystone which disrupts the stratification and produces a brecciated appearance. Brecciation appears to have been caused by load compaction. This type of load deformation is common between sandier and muddier beds throughout the entire Tertiary section in this region.

Primary structure, except for a vague, discontinuous layering, is almost lacking in this facies of the Pittsburg Bluff Formation. The muddy sandstone appears to have been thoroughly reworked by burrowing organisms. Two miles east of this locality along the Spokane, Portland, and Seattle Railroad, the Pittsburg Bluff Formation grades upward into coarse-grained pebbly sandstone, which is pumiceous and contains abundant plant debris. The sandstone is overlain locally by basaltic pebble to boulder conglomerate at the base of the overlying Scappoose Formation. In this region the Pittsburg Bluff Formation is about 800 feet thick.

The Pittsburg Bluff Formation appears to have been formed in a deltaic environment.

1.3

30.4 On right, upper part of road cut is stained red by thorough weathering of overlying

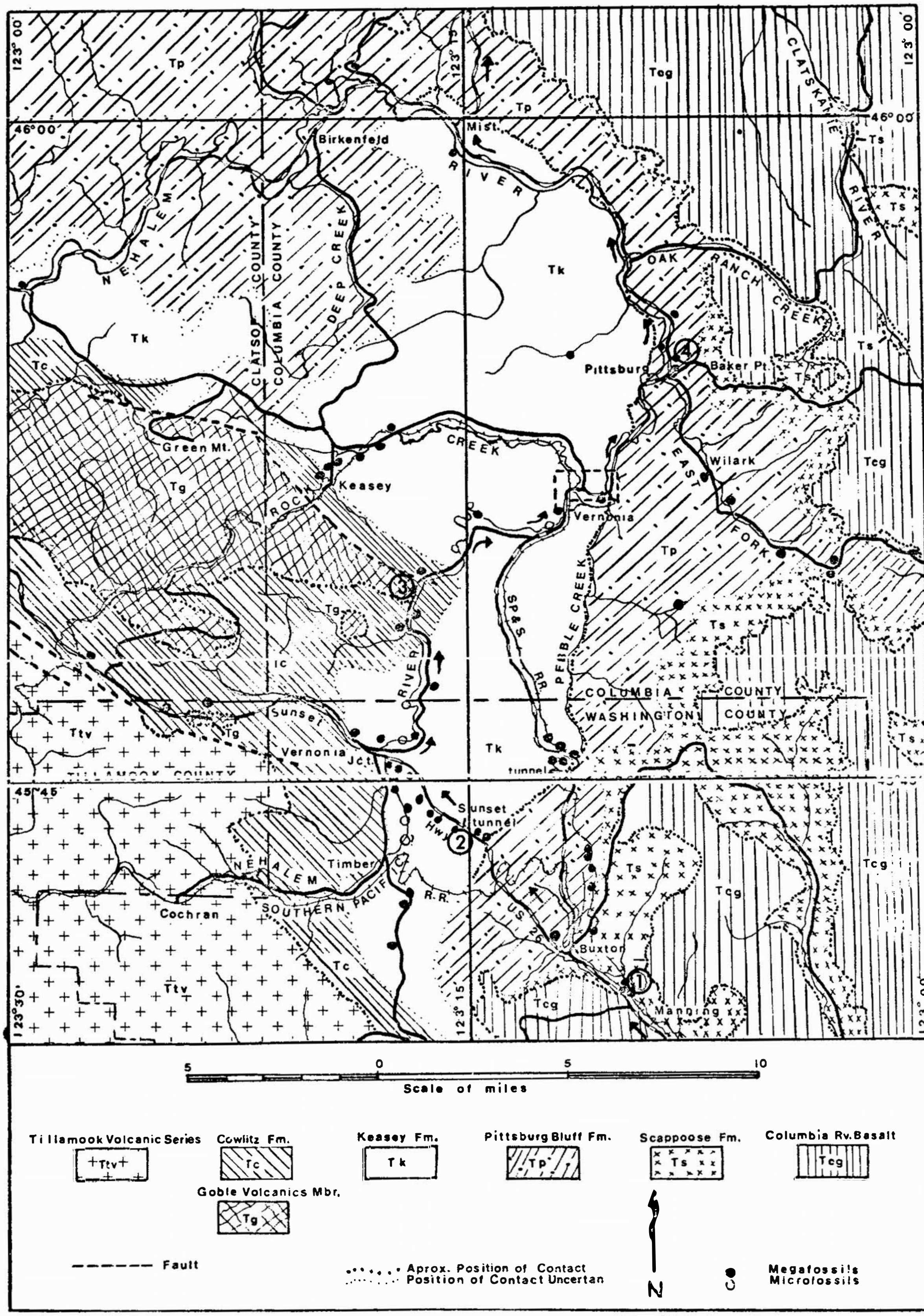


Figure 2. Geologic map of upper Nehalem River basin, northwestern Oregon, revised from Warren and Norbisrath (1946) by Van Atta (1971).

basalt of the Columbia River Group. Remnants of the basalt can be found in low spots in the pre-Columbia River Group topography carved in the gently folded Keasey, Pittsburg Bluff, and Scappoose Formations. At many places in this region basalts of the Columbia River Group rest directly on the Pittsburg Bluff Formation; the Scappoose Formation has been completely eroded away. Several basaltic feeder dikes related to the flow or flows which once covered this immediate area are found nearby. The topography here on what has been called the Scofield surface (Van Atta, 1971a, 1971b) is relatively gently rolling. It appears that a local flow on a stripped structural plane protected the softer underlying sediments until recently when weathering and erosion finally allowed streams to begin dissection.

1.2

31.6 On right, small pond in trees is related to one of the number of springs which occur along the contact between the relatively impermeable Keasey Formation mudstones and the overlying siltstones at the base of the Pittsburg Bluff Formation. Although facies changes are common throughout all of the muddy Tertiary sediments of this region, the relatively clean, finely laminated lithic or arkosic siltstone at the base of the Pittsburg Bluff is persistent for a number of miles north and south at this point.

0.8

32.4 On left, road cut exposes tuffaceous mudstones of the Keasey Formation (upper Eocene - early Oligocene). Limey concretionary beds are prominent in most outcrops of the Keasey Formation throughout northwestern Oregon while the Pittsburg Bluff Formation in this part of the upper Nehalem River Basin rarely has concretionary beds.

0.5

32.9 Sunset Tunnel, eastern portal. The uppermost part of the Keasey Formation, because of the presence of numerous concretionary beds, is much more resistant to erosion than the mudstones of the middle part of the formation or the overlying Pittsburg Bluff Formation. As a consequence, a prominent ridge runs northeast-southwest in this area. Railroads must cross this ridge through tunnels. To the west the relief is much more highly dissected. It is probable that the presence of capping basalt flows on the Scofield surface and the absence of such flows to the west of the ridge may account for the difference in topography.

0.3

33.2 STOP 1-2, on left. Pit and plant of Empire Lite Rock Company in middle member of Keasey Formation. The fossiliferous, concretionary mudstone exposed here is typical of most of the Keasey Formation throughout northwestern Oregon. Dips are consistently southeast 10-12° and the strike is northeast. The middle member of the Keasey Formation is about 1,800 feet thick in this region. Mollusks (Nemocardia weaverii and Delectopecten) and foraminifera are abundant in this quarry. For a listing of fossils, see appendix.

Empire Lite Rock crushes the rock to nut-size and runs it through oil-fired rotary kilns to produce a $1\frac{1}{2}$ to 2-inch expanded briquette which can be crushed and used as light-weight aggregate for concrete building blocks. Clay present in the Keasey mudstones is almost entirely expandable montmorillonite. Where the rocks are exposed to alternate wetting and drying, slaking produces disintegrated mass of chips.

0.6

33.8 Road cuts for the next 0.5 mile are in the middle member of the Keasey Formation.

0.5

34.3 Landslide area for the next 0.4 mile in middle member of Keasey Formation. During wet seasons slides are a continual problem in the Keasey Formation. Smectitic clays may make up from 35 to 40 percent of the rock, which renders it very susceptible to slumping on oversteepened slopes where water infiltration is great.

In the summer of 1972, the roadbed was widened and the slope of the cuts reduced to stabilize the road.

1.6
35.9 Bridge over Nehalem River. The contact between the lower member of the Keasey Formation and the upper shale member of the Cowlitz Formation (upper Eocene) has been mapped in this vicinity by Warren and Norbisrath (1946) based on the break between Narizian and Refugian faunas. The nearly identical lithology of these two units, however, makes differentiation in the field nearly impossible. Both are predominantly mudstone. On the basis of lithology it seems better to combine the mudstones and sandy siltstones of both the lower member of the Keasey Formation and the upper shale member of the Cowlitz Formation into the lower Keasey (Figure 3). The break between Narizian and Refugian faunas would then occur above the lithologic break within the newly erected lower member of the Keasey Formation.

0.2
36.1 Junction, Timber-Vernonia Road. Turn right off U. S. 26 toward Vernonia.

0.2
36.3 At 11 o'clock, note large landslide scar in lower member of the Keasey Formation. The slide area occurs in conjunction with a large fault and undercutting by the Nehalem River.

1.9
38.2 On left, stream bank across Nehalem River in lower member of the Keasey Formation.

0.4
38.6 On right, road cut in pillow basalt and muddy sandstone in lower member of Keasey Formation.

0.6
39.2 On right, large road cut in fossiliferous concretionary muddy sandstone and siltstone of lower member of the Keasey Formation.

1.4
40.6 On left, a good view of Clear Creek valley. Highest hills are in the Goble Volcanics member of the Cowlitz Formation (upper Eocene). This was mapped as the Tillamook Volcanic Series (Warren and others, 1945), but the uppermost group of basaltic flows are clearly interbedded with sediments of the Cowlitz Formation, just as in the type locality of the Cowlitz Formation, 35 miles north. There, Henrikson (1956) regarded the Goble Volcanics as subordinate to the sediments of the Cowlitz and designated the Goble as a member of the Cowlitz. A similar relationship between basaltic flows and sediments exists to the south in the Nestucca Formation (also upper Eocene).

0.3
40.9 At 3 o'clock on skyline, Rocky Point is an up-faulted block of Cowlitz Formation sandstones and siltstones interbedded with olivine basalts of the Goble Volcanics member. The two large quarries visible near the top are in intrusive bodies of Goble Volcanics basalt.

0.3
41.2 Bridge over Nehalem River. Junction with Clear Creek Road. Keep right on Timber-Vernonia Road. The west bridge abutment is in dark bluish-gray fossiliferous, pumiceous mudstone of the lower member of the Keasey Formation. Fossils here include crustacea, mollusca, and abundant foraminifera. The beds strike N. 25° W. and dip a few degrees northeast.

0.6
41.8 STOP 1-3: Junction, Rocky Point Road. Park in field to left and walk along lower road to Columbia County quarry. Here basalts of the Goble Volcanics member are interbedded with bentonitic mudstone below and boulder conglomerate above, both of the Cowlitz Formation. The presence of pyrite, zeolites, and calcite in the upper part of the basalt unit and the lower part of the conglomerate suggests a possible intrusive relationship.

The Eocene brachiopod, *Terebratalia*, is found with oysters and other pelecypods, gastropods, hexacorals, fish teeth, and some unidentified vertebrate bone fragments in

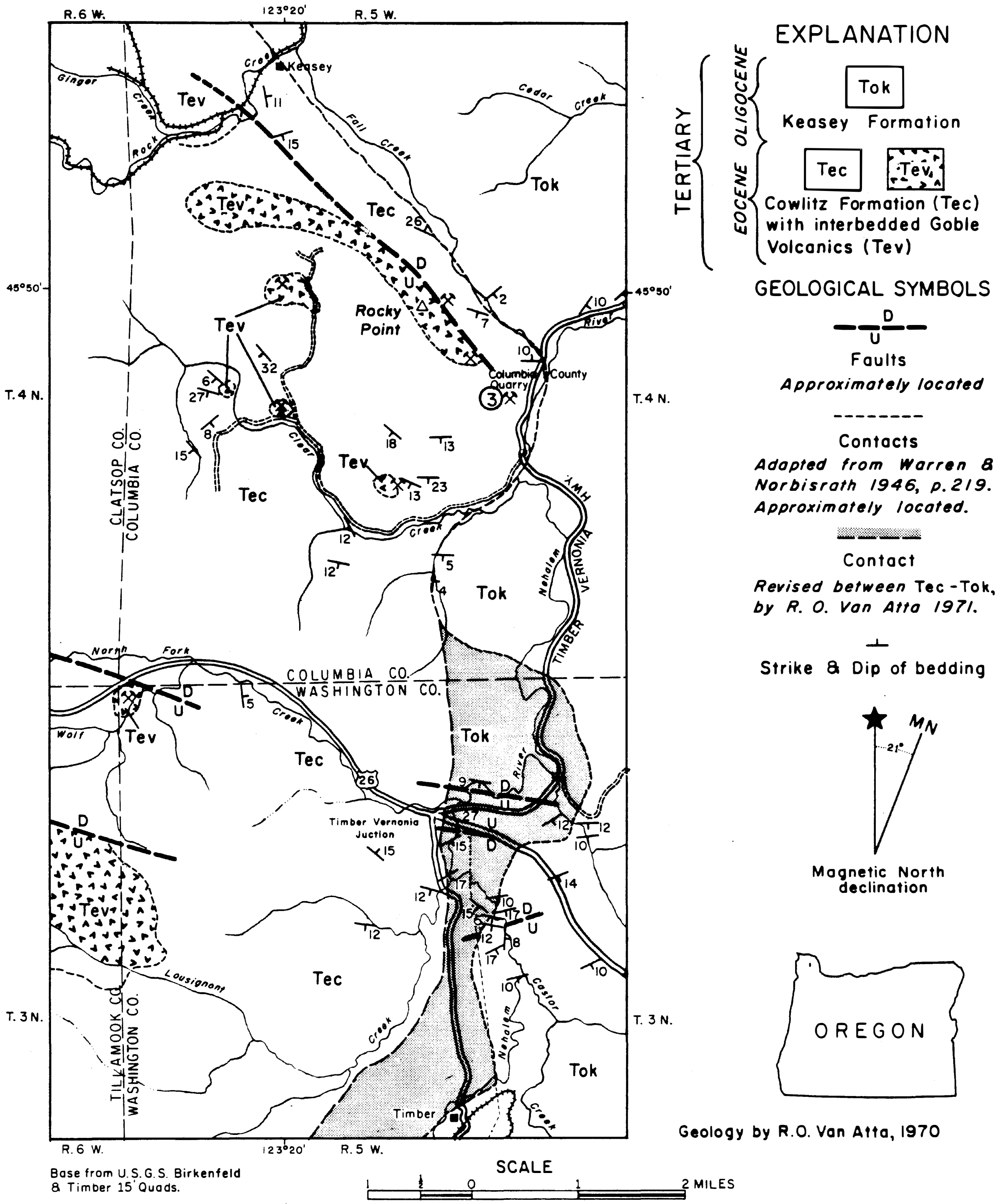


Figure 3. Geologic map of part of the upper Nehalem River basin, Oregon. Stippled area originally mapped as Cowlitz Formation by Warren and Norbisrath (1946) considered part of Keasey Formation by Van Atta (1971).

the pebbly parts of the conglomerate. Fossiliferous boulder conglomerates are common in many places in the upper Nehalem River basin where the Goble Volcanics member is interbedded with sediments of the Cowlitz Formation. At some localities along Clear Creek, pillow structure and admixed masses of plastically deformed mudstones are found in basalt intrusions and flows which were contemporaneous with Cowlitz sedimentation. See appendix for list of fossils.

1.0

42.8 On left, a few low road cuts, for the next 0.9 mile, expose light-colored medium- to fine-grained arkose of the sandstone member of the Cowlitz Formation. Most outcrops of the arkose show less than 5 percent matrix and are highly permeable. The sandstone contains a fair amount of plant debris but is otherwise unfossiliferous.

3.5

46.3 Junction, turn left to Vernonia on Oregon Highway 47.

1.6

47.9 Entering Vernonia.

0.5

48.4 On the right, just before Rock Creek bridge in downtown Vernonia, see one of the old Long-Bell Lumber Company's steam locomotives. In the early days of logging, continuing up to the 40's, many miles of railroad were the chief means of bringing logs to the mill.

0.1

48.5 Junction, Keasey Road, to type locality of Keasey Formation. Keep straight on Oregon Highway 47.

0.2

48.7 On left, road cut in Keasey Formation.

0.6

49.3 Bridge over Nehalem River. Junction, Pebble Creek Road. Turn left on Oregon Highway 47 to Mist.

0.9

50.2 On right, hills across flood plain of Nehalem River composed of the Pittsburg Bluff Formation. Topography in the more competent sandstones and sandy mudstones of the Pittsburg Bluff shows more relief than in the incompetent mudstones of the Keasey Formation to the left (west). The road more or less follows the contact between the two formations for several miles.

The highest hill straight ahead is in basaltic flows of the Columbia River Group.

1.1

51.3 Junction with Keasey Road (left). Keep straight on Oregon Highway 47.

0.9

52.2 On right, across Nehalem River, outcrops of Pittsburg Bluff Formation. This is part of the type locality.

0.1

52.3 On left, Pittsburg Forest Guard Station, State Department of Forestry. This is the site of the old logging town of Pittsburg. Crown Zellerback's Peter Stamm Tree Farm Headquarters is here.

0.4

52.7 Junction, Crown Zellerbach private mainline road. Keep straight on Oregon Highway 47. Most logging companies have their own system of roads, many of which have extensive cuts, making field work for the geologist much easier than in the past. Altogether Tertiary formations of this region are much better revealed along the newer logging roads than along the highways and streams.

0.1

52.8 Bridge over East Fork Nehalem River. Junction, Scappoose Road. Keep left on Oregon Highway 47 to Mist.

0.4

53.2 STOP 1-4: Pull off on left shoulder and walk back to road cuts on right. BEWARE of traffic. This is near the base of the Pittsburg Bluff Formation. The tuffaceous and arkosic sandstone is massive to finely cross-laminated. Fossil mollusks, wood, and some coaly material are common. Along Coal Creek, in the vicinity of Vernonia, lignitic coal was mined in the past for local consumption. Where molluscan remains are common, the sandstone tends to be concretionary and glauconitic. Some laminae are almost entirely glauconite. The fauna of the Pittsburg Bluff Formation has been studied intensively in this area during the past 80 years. Dall (1909) first described the fauna here in correlating these rocks with the "Miocene(sic) of Coos Bay".

The arkosic sandstones of the Pittsburg Bluff Formation appear to be restricted to the type locality and vicinity. Elsewhere, the rocks tend to be sandy mudstones and siltstones. East of the Nehalem River between Pittsburg and Vernonia chaotic bedding, conglomerates, intraformational sedimentary breccias containing mudstone blocks up to 3 feet in length, torrential cross-bedding, and cut-and-fill structures are common in the Pittsburg Bluff Formation. Warren and Norbisrath (1946) considered the fauna to be indicative of a brackish water environment. It seems probable that the formation is of deltaic origin.

0.7

53.9 On right, highest hills on skyline are in Columbia River Basalt. At many points, the Scappoose Formation, which stratigraphically underlies the basalt, is missing and the Columbia River Basalt rests upon the Pittsburg Bluff Formation.

0.5

54.4 On the right, road cuts in sandy mudstone of the Pittsburg Bluff Formation. This is identical to the rock type seen at the first stop on the Sunset Highway (U.S. 26). The yellow mottling, molluscan fossils, carbonized wood, and high percentage of volcanic glass are the same. The road follows the flood plain of the Nehalem River for a number of miles where the Nehalem River flows westward. The course of the Nehalem nearly describes a full circle as it circumscribes the uplifted mass of upper Eocene volcanic and sedimentary rocks south and west of the upper Nehalem River basin and very closely follows the contacts between the Cowlitz and Keasey Formations and the overlying Pittsburg Bluff Formation. The lower reaches of the river are within 8.5 miles of its headwaters. The Salmonberry River, a major tributary, flows westward into the lower reaches of the Nehalem and has its headwaters less than half a mile from the headwaters of the Nehalem River. Another major tributary, Rock Creek, which flows eastward and empties into the Nehalem at Vernonia, has its headwaters only 4.5 miles from the middle reaches of the Nehalem (see index map, Figure 2).

2.2

56.6 Junction, Apiary-Rainier Road. Keep straight on Oregon Highway 47 to Mist.

1.4

58.0 On right, road cut in bioturbated mudstone, lower Pittsburg Bluff Formation. At far end of cut a thin lens of pumiceous claystone crops out at eye level.

1.4

59.4 On right, large road cut in lowermost part of Pittsburg Bluff Formation exposes a muddy, fine-grained arkosic sandstone. The rock is finely cross-laminated, with thin shaly lenses. Plant fragments are abundant. Abrupt facies changes, such as that between this exposure and the previous one, are common in these Tertiary formations.

3.1

62.5 On left, across Nehalem River, light-colored bluffs visible for the next 0.7 mile are outcrops of the Keasey Formation. This is the locality near Mist, Oregon, where crinoid, asteroid, and coral fossils are found (Moore and Vokes, 1953). See appendix for for list of fossils.

0.7

63.2 Junction with Burns Road. Keep straight on Oregon Highway 47. The Mist crinoid locality can be reached by crossing bridge and walking upstream along river bank.

0.2

63.4 Mist. Junction with Oregon Highway 202. Keep right on Oregon Highway 47 to Clatskanie.

1.5

64.9 At 2 o'clock, outcrop across a steep-walled canyon is in the Pittsburg Bluff Formation. Incompetent mudstones here allow the development of a very rugged relief once streams manage to erode through the overlying Columbia River Basalt.

0.6

65.5 On left, for the next 0.6 mile, road cuts are in sandy mudstones of the Pittsburg Bluff Formation. The strike here is east-west, and dip is 15 degrees north. There is a faint discontinuous layering which marks the bedding planes. For the most part the thickest beds are bioturbated. Clasts of clay and coarse pumiceous sandstone with leaf fragments, worm-bored carbonized wood, molds of mullusca, pumice pebbles, and an overall yellow mottling make these beds almost identical to those at the first stop on U.S. 26, except that this mudstone has more carbonized material.

0.6

66.1 On left, beds of upper Pittsburg Bluff Formation show better stratification than in road cuts just passed. The strike continues east-west, but the dip is steeper, 25 degrees north.

0.1

66.2 On left in road cut, sandy, pebbly mudstone of the Pittsburg Bluff Formation with much brown plant debris is interbedded in its upper part with sandy pebble conglomerate of the Scappoose Formation. Discoidal clasts in the conglomerate are mudstone and muddy sandstone, probably derived from these same beds nearby. The sandy pebble conglomerate beds and lenses are quite thin (4 to 8 inches) and are interbedded with arkosic muddy sandstone. Arkose of the Scappoose Formation lies above the Pittsburg Bluff Formation. The change in lithology between the two formations here is analogous to that in the Buxton-Manning area, which was passed in the early part of this trip (mile 25.6).

0.8

67.0 Junction, Enterprise Road. Keep straight on Oregon Hwy. 47.

0.2

67.2 STOP 1-5: Entering area of large landslide. In the spring of 1972 the entire road section here was swept away; the slide extended down the gully to the left for hundreds of yards. The first step in restoring the road was to dig out the muddy sand in the upper part of the slide and back-fill with pit-run brickbat-jointed Columbia River Basalt. Paving was restored and the next step, at the time of this writing (September, 1972), is to reduce the slope on the cuts to the right of the road. The rock here is uncemented, highly friable yellowish micaceous lithic arkose of the Scappoose Formation. The beds are up to 12 feet thick and faintly cross-laminated. No fossils other than leaf and wood fragments are present.

0.4

67.6 Junction, Conyers Road. Keep straight on Oregon Highway 47. Road cuts on left for the next 0.7 mile are in yellowish cross-laminated arkose of the Scappoose Formation.

0.7

68.3 On left in road cut, brickbat-jointed Columbia River Basalt lies in a low in the pre-Columbia River Group topography, which was eroded into the upwarped Scappoose, Pittsburg Bluff, and Keasey Formations in northwest Oregon.

0.6

68.9 On left, road cut in Columbia River Basalt and Scappoose Formation arkose. The contact is not very distinct but can be seen toward the upper end of this small cut. For the next 0.4 mile road cuts are in arkosic sandstone of the Scappoose Formation.

0.4

69.3 On left, road cut in colluvium and soil, Columbia River Basalt, and Scappoose Formation.

0.1

69.4 On left, road cut in Columbia River Basalt.

0.8

70.2 On left, road cuts in pebbly arkose of Scappoose Formation.

0.2

70.4 Longview Fibre Tree Farm.

0.9

71.3 On left in road cut, old landslide has incorporated large unweathered blocks of basalt and arkosic sandstone mixed with thoroughly weathered vesicular boulders and cobbles of basalt.

0.7

72.0 On left, road cut showing vertical contact between Columbia River Basalt and arkosic sandstone of Scappoose Formation. Notice the undulating contact, which appears as an embankment against which the basalt flowed. This is an excellent example of the burial of the old topography by the basaltic lava flows.

0.5

72.5 On left, large road cut in mottled sandy mudstone. Lithologically this is the same as the sandy mudstone of the Pittsburg Bluff Formation elsewhere. Here Fall Creek, on right, has apparently cut down below the Scappoose Formation into older beds. To the southeast, on Conyers Creek, Warren and others (1945) correlated conglomerate and massive sandstone beds with the Gries Ranch Formation of the early Oligocene of southwest Washington on the basis of faunas "unlike those of the Keasey Formation and older than those of the Pittsburg Bluff Formation" (Baldwin, 1964, p. 14).

1.3

73.8 Road junction, keep straight on Oregon Highway 47. Road cuts reveal cross-laminated arkosic sandstone with large fragments of carbonized wood, leaves, and laminae of black carbon. Lithologically this looks like the Scappoose Formation, but it would be too low stratigraphically considering the previous road cuts in Pittsburg Bluff mudstone.

0.5

74.3 On right in small quarry, sandy cobble conglomerate is overlain by pale yellowish, mottled sandy mudstone which looks a great deal like the Pittsburg Bluff mudstones. Fossils are not reported here, although detailed work might reveal some. This may correlate with the Gries Ranch-age conglomerate and mudstone along Conyers Creek, less than 2 miles to the southwest. However, 0.2 mile from here toward Clatskanie, this conglomerate appears to overlie the Columbia River Basalt and therefore probably is part of the Troutdale Formation.

Holes have been excavated in the conglomerate by agate hunters who have more courage than most of us. Quartzite pebbles and cobbles are prominent in the conglomerate but are not as abundant as in the Troutdale Formation in the St. Helens area southeast of here. The most abundant clasts are volcanic rock fragments of basalt and andesite.

0.1

74.4 On right, more conglomerate in road cut.

0.4

74.8 Clatskanie city limits.

0.4

75.2 Junction with U.S. Highway 30. Turn right on U.S. 30 to Rainier, Oregon.

0.4

75.6 Bridge over Clatskanie River. In NE $\frac{1}{4}$ of sec. 36, T. 7 N., R. 4 W., Columbia County, Oregon on Conyers Creek about 3 miles south of Clatskanie, in 1945 the Texaco Company drilled Clatskanie no. 1 to a total depth of 5,650 feet (see Figure 4, in pocket).

Newton (1969) reports the following well data: "Oily odor in volcanic breccia 730-700 feet, no cut (could have been contamination). Gas and oil show 1394-1401 feet. Gas show 2159-2170 feet. Light yellow ether cut from sample 5114-5146 feet. Core had no odor. No formation tests run. Reamer stuck in the hole at 5640 feet. Hole had to be abandoned."

1.1

76.7 On left high in road cut, landslide scar in conglomerate and mudstone.

0.4

77.1 On left in large road cut, muddy arkosic sandstone is finely laminated, contains clay clasts, and some well-sorted, highly polished, well-rounded pebbles in discontinuous layers. About half-way up the road grade a large piece of carbonized wood with some coaly material in a thin bed below it can be seen near the road level.

4.7

81.8 Junction. Lost Creek Road. Keep straight on U.S. 30. The road now enters the broad Beaver Creek valley atop flows of the Columbia River Group.

0.8

82.6 Bridge over Beaver Creek.

1.4

84.0 Road cuts in brick-red soil derived from Columbia River Group basalts.

1.5

85.5 At 11 o'clock, excellent overview of Longview bridge. The road descends from here to Rainier, Oregon. On the right, road cuts are first in Columbia River Group Basalt (in places possibly later than Yakima) and then in Goble Volcanics. At the upper and lower ends of the road cut, fans of columnar jointing are visible. Near the exit to the bridge, dark fossiliferous sandstone of the Cowlitz Formation crops out.

1.2

86.7 Exit to Longview Bridge. Turn right and cross bridge. On the right at 1 to 2 o'clock is the Port of Longview(Washington). On the left at 10 o'clock is the Reynolds Metals Company aluminum reduction plant and Weyerhaeuser lumber and paper mills. Bridge is high enough that ocean-going steamers can pass underneath on their way to and from Portland, Oregon, one of the main west-coast seaports.

1.0

87.7 East end of the Longview bridge. The low hills straight ahead are called Columbia Heights; they are underlain by the Cowlitz Formation and capped by Columbia River Basalt. The low hills at about 1 o'clock make up Mount Brynion. They are underlain by the Cowlitz Formation and capped by the Goble Volcanics. The Cowlitz River enters the Columbia River valley at about 1 o'clock and makes one large meander to the east before entering the Columbia River. The Coweman River enters the valley of the Columbia River at about 2 o'clock. The Coweman is a much smaller river, running parallel to the Cowlitz for about 2 miles before it enters the Cowlitz one mile from the Columbia River. Because the three rivers are about the same elevation as the Longview and Kelso business districts, levees have been built by the U.S. Corps of Engineers to prevent flooding. The Columbia River silts up rapidly, and as a result the Corps has a continuous dredging program on the river to maintain the channel depth that is necessary to accommodate ocean-going vessels. The average discharge of the Columbia River at Longview is estimated to be in excess of 250,000 cubic feet per second. Peak discharges at the Dalles during the floods of 1894 and 1949 were 1.250 million and 1.010 million cubic feet per second respectively. At Kelso, the discharge of the Cowlitz River is 8,772 cubic feet per second, and the Coweman discharge is 380 cubic feet per second.

0.4

88.1 Traffic signal on Oregon and Industrial Way, turn right on Industrial Way. Elevation is about 10 feet above sea level. During normal runoff, the Columbia River surface is at about 10 feet also. The river at this point is affected by the tide, so its surface elevation varies from time to time during the day.

1.0

89.1 Turn left on 3rd Avenue.

0.4

89.5 Turn left onto Highway 432 entrance ramp toward Vancouver. Head east toward Interstate 5.

0.3

89.8 On left is the levee, which was built in 1923-1924 along the west bank of the Cowlitz River. The fill used to make the highway over which we are traveling was dredged from the river by the Corps of Engineers. The fill is mostly sand and has very little gravel mixed with it.

1.6

91.4 Approach to the Cowlitz River bridge. Fill leading to the bridge is made up of sand dredged out of the Columbia River.
Left toward Seattle. Head toward the large road cut at 12 o'clock to 1 o'clock.

1.0

92.4 Overpass over Interstate Highway 5.

0.1

92.5 Continue to the left on the Rose Valley-Carroll's Bluff highway.

0.1

92.6 Under overpass and turn to the left onto the road that parallels Interstate 5 back to the north toward Kelso.

STOP 1-6: Park on large pull-off at north end of road cut. The outcrops on the east side of the interchange expose several faults and different lithologies of the Goble Volcanics (Figure 5). Beginning at the south end of the road cut and going north, the geology is as follows: altered basalt, part appears to be palagonitic and may have pillow structures in it near the top of cut. Below it is a harder, fresher basalt that is probably a dike or sill. The more altered part of the flow is shot full of white veinlets of calcite and zeolitic material. A hundred feet north from the beginning of the road cut, a contact is crossed between the soft altered basalt and a columnar basalt. The columnar basalt is less altered and more resistant. It is evenly vesicular throughout and looks like a dike, but it may be a flow. The columns give the impression that the body dips to the south. Alteration along the south contact zone has produced a light green to brown clay. The columns are extremely well-developed where their cross sections are exposed at the northernmost exposure of this unit. The north end of the columnar basalt is truncated by a fault that runs vertically up the hill. North of the fault there is a small wedge-shaped sliver of sandstone at the base of the road cut, and a soft, altered, irregularly jointed basalt in the upper part of the cut. The sandstone and basalt are bounded on both sides by faults. North of the soft, altered, irregularly jointed basalt, which may strike north-northwest and dip southeast, is a soft, black, altered basalt that contains abundant north-south-striking, east-dipping shear planes. Some thin interbeds of tuff and carbonaceous shale are present and slickensides are abundant. North of the basalt is a contorted and sheared sandstone and carbonaceous shale. The sandstone encloses a lens of altered black basaltic sandstone near the base of the cut. At the north end of the sandstone is another fault. The carbonaceous shale beds, which are west-dipping here, are easily seen. At the north end of this unit is yet another fault that separates the sedimentary rocks from a massive dark, soft, altered flow breccia and volcaniclastic rock. The main joints strike about 40° east and dip 50° northwest. Spheroidal weathering and shearing is common. This is probably a flow that spilled out onto the floor of the Eocene sea.

Over the top of the bedrock in this road cut is a remnant of the Troutdale Formation. The little cirque-like bowl in the upper slope above the bedrock is the result of a landslide in the Troutdale unit. The Troutdale Formation has been dated as Pliocene, using leaf fossils at its type locality. In the Kelso-Longview area it is made up of two members -

Age	Formation	Lithologic character	Map symbol	Thickness (feet)
Recent	Alluvium	Gravel, sand, and silt deposits along streams. Includes peat bogs in the Columbia valley west of Longview.	Al	250±
		Unconformity.		
Pleistocene	Landslide debris	Heterogeneous mixture of detached Tertiary bedrock and Quaternary deposits.	Ls	
		Unconformity.		
	Terrace deposits	Fine sand and silt along the Cowlitz and Coweman Rivers.	Qt	160±
		Unconformity.		
Pliocene	Post-Troutdale silty clay	Massive light-brown clayey silt, upper part; and red to mottled red and gray heavy silty clay, lower part. In most places has a gibbsitic pisolitic zone at base.		40±
		Unconformity.		
	Troutdale Formation	Poorly consolidated conglomerate, gritstone, sandstone, and claystone. Scattered quartzite pebbles and cobbles are diagnostic of the formation.	Tt	900
		Unconformity.		
Miocene	Columbia River Basalt	Dense black aphanitic basalt, vesicular in part, columnar and blocky jointed, and containing occasional sandstone and conglomerate interbeds. Gives way to marine sediments to the west.	Tcr	1,400±
		Unconformity.		
Oligocene	Oligocene sedimentary rocks	Massive dark- to light-gray siltstone.	To	?
Eocene--Oligocene	Goble Volcanics	Basaltic flows, flow breccia, pyroclastic material, and intercalated sedimentary beds.	Tgr	1,000±
Eocene	Cowlitz Formation	Massive to thin-bedded arkosic sandstone, siltstone, and shale, also some conglomerate, gritstone, and volcanic sandstone. Contains coal locally. Formation is coarser to the east. Basaltic unit, which is made up of flows, pyroclastic and sedimentary rocks, interfingers from south.	Tc Tcv	1,800+
	Older Eocene volcanic rocks	Light-gray-weathering, soft, chloritized basalt flows.	Ev	?
		INTRUSIVE IGNEOUS ROCKS		
Post-Cowlitz	Dikes and plugs	Basaltic dikes and glassy basaltic plugs.	Ti	
Tertiary	Hypabyssal intrusive	Monzonite to quartz monzonite plug.	Tig	

Figure 5. Stratigraphic sequence in the Kelso-Cathlamet area, Washington.

a lower conglomerate member and an upper sandy member. The Troutdale is a valley-fill unit and remnants of it can be found plastered against the walls and up the side valleys of the Columbia River valley. It is characterized by the presence of abundant quartzite pebbles that probably were derived from northeastern Washington.

0.4

93.0 Turn right onto Kelso Drive and continue north.

0.2

93.2 Road cut is in volcaniclastic rocks or flow breccias of the Goble Volcanics. Beds strike about north 45° east and dip 10° to 15° to the southeast.

0.3

93.5 On the right is a good exposure of a volcaniclastic rock, typical of the Goble Volcanics, overlying a light-tan friable sandstone that is typical of the Cowlitz Formation. The contact between the Cowlitz and the Goble is typified by an inter-fingering relation where the sandstone beds of the Cowlitz gradually decrease in number upsection and give way to volcanic rocks of the Goble.

0.2

93.7 On the right are outcrops of a dirty basaltic sandstone to gritstone.

0.1

93.8 On the right are outcrops of light-tan sandstone of the Cowlitz Formation underlying the basaltic sandstone.

0.2

94.0 Tuffaceous or basaltic sandstone to gritstone underlain by the typically light-tan sandstones of the Cowlitz. From here northward to the city of Castle Rock (about 9 miles), the road cuts are primarily in Cowlitz Formation sandstone. The sandstones are generally deeply weathered and friable. The shoreline of the sea at the time this material was deposited was just slightly to the east, probably not more than a mile and a half to 2 miles away. The fossils found in these sands are marine to brackish water types such as clams, oysters, and snails. The fossils in the area are poorly preserved and very difficult to find. In most cases, the shells have been leached away and all that remains is the external cast. Enough fossils have been found, however, to definitely date the formation as upper Eocene.

0.3

94.3 Intersection with Interstate 5. WITH CAUTION cross Interstate 5. To the right, after crossing, one of the common problems that beset highway construction in western Oregon and Washington can be seen, that is, slope failure. In this case, the landslide has been buttressed by using large chunks of columnar basalt to shore up the toe of the slope to prevent further movement.

0.7

95.0 On the right is black, slightly altered basalt with fairly good columnar jointing. This is a flow within the Cowlitz Formation. Typically the flows in the Cowlitz are thin, vesicular, and have scoriaceous tops. They are hypocrystalline and cumulophyric. The groundmass is intersertal to intergranular. Average mineralogic composition is plagioclase, 48 percent; augite, 28 percent; glass, 12 percent; opaque grains, 9 percent; and alteration products, 3 percent. This is for all practical purposes identical to the Goble.

0.2

95.2 Bridge over the Coweman River. Note the levee on the north bank of the river and how much lower the golf course is than the river level. Levee was constructed from dredge spoil in 1915. The pond in the golf course is a remnant of a stranded meander of of the Cowlitz River. Air photos of this area show numerous meander scars left by the Cowlitz River.

0.4

95.6 Turn to the left on to Mill Street.

0.4

96.0 Turn right on 4th Avenue.

0.7

96.7 Turn left onto Cowlitz Way (Washington Highway 4).

0.1

96.8 Cross Cowlitz River. Notice that the road going up the west bank of the Cowlitz River is on top of the levee. The hill to the right is Columbia Heights. Base of the hill is made up of Cowlitz Formation volcanic rocks, middle part is made up of Cowlitz Formation sandstone, and top is capped by Columbia River Basalt. Get in right lane, preparatory to turning to the right on Highway 4 to Long Beach, Washington.

0.6

97.4 Turn right onto Ocean Beach highway.
Entering Longview, Washington.

1.2

98.6 On left is Lake Sacajawea, named after the famed Indian lady who helped guide Lewis and Clark on their expedition to the Pacific Ocean. Lake Sacajawea is a stranded oxbow of the Cowlitz River, and loops to the south and southeast for about $1\frac{1}{2}$ miles. The city of Longview has constructed a park on both sides along its entire length.

0.6

99.2 Ahead at 12 o'clock is Mount Solo. This hill was left stranded by the Columbia River as it downcut its valley, probably during early Pliocene times. At one time the river ran on the north side of the mountain. The base of Mount Solo is in Cowlitz volcanics, which are petrographically indistinguishable from Goble Volcanics. The middle part of the hill is made up of Cowlitz Formation sandstones, and the top is capped by Columbia River Basalt. The deep road cut that can be seen at the east end of the hill is entirely in Cowlitz volcanics.

1.2

100.4 Junction of 38th Avenue and the Ocean Beach Highway. Stay on the highway.

0.3

100.7 At 9 o'clock, terrace midway up Mount Solo is a landslide.

2.0

102.7 Top of levee. Levee was built in 1923-1924 and is made up of sand and silt dredged from the Columbia River.

0.2

102.9 Ahead at 1 o'clock, near the middle of the hill at the top of the quarry cut, the unconformable contact between the Columbia River Basalt and the underlying sandstones of the Cowlitz Formation can be seen.

0.3

103.2 At 1 o'clock to the right, are excellent exposures of Cowlitz sandstone along the dirt road.

0.2

103.4 On the right, large blocks of Columbia River Basalt that have slid down the hill.

1.1

104.5 Outcrops on the right of the road are in Cowlitz volcanic flows. The flows are indistinguishable petrographically from Goble Volcanic flows. The flows strike about north-south and are exposed in the core of a gently folded anticline. Dips here are about 10° to the east; dips on the west flank of the anticline are same magnitude. The area to the right of the road is known as Bradley Heights. It is capped by Columbia River Basalt of Miocene age upon which a layer of loess was deposited in Pliocene times. The loess unit is probably correlative with the Portland Hills Silt.

In this area, as well as in Oregon the top flows of the Columbia River Basalt have been weathered and altered to form ferruginous bauxite-laterite. There are three basic types of ferruginous bauxite -- earthy, nodular, and pisolitic. The color varies from mustard-yellow to brown to various shades of red. The ferruginous bauxite is composed of a mixture of gibbsite and reddish iron oxide. Locally, small doubly terminated quartz crystals are found in the upper part of the bauxite section.

1.4

105.9 STOP 1-7: Alder Bluff. Pull off into quarry in Columbia River Basalt on right. The Columbia River Basalt usually stands out in bold outcrops along valley walls. Typically, it is hyalo-ophitic textured and non-porphyritic. The most striking petrographic feature is its high glass content -- up to 60 percent in some rocks. The bottom part of the quarry is in massive hockly jointed basalt which according to Snavely and others (1973) is Yakima-type basalt. The top port of the quarry exposes columns of basalt which according to Snavely and others (1973) is basalt of Pack Sock Lookout. The columns of the top flow exposed in the quarry are bent to the south. According to Waters (1960), this indicates that the lava flow was moving southward at the time it chilled. Notice in the center of the quarry that the bottom basalt flow was channeled, and the channel filled with sand and gravel before the next flow covered it.

0.3

106.2 Columnor basalt exposed on the right side of the rood is in the Cowlitz Formation.

0.5

106.7 Outcrops at 1 o'clock are in Columbia River Basalt. All outcrops that are seen from here to Cathlamet are either Columbia River Basalt or sedimentary interbeds in the basalt.

1.7

108.4 Rock quarry in Columbia River Basalt on the right, capped by a well-exposed sandstone interbed between basalt flows. The rock quarried out of this particular pit was used as jetty stone by the Corps of Engineers along the Columbia River. The jetties are built out into the river normal to the bank and collect sand by accretion.

1.4

109.8 Bridge over Abernathy Creek. Abernathy Creek is thought to have cut its way along a northwest-trending strike-slip fault. The foult is thought to extend about 10 miles to the northwest. The creek has a remarkably straight alignment over its length.

0.4

110.2 Bridge over Mill Creek. At 1 o'clock a sedimentary interbed can be seen; it is somewhat unstable and has a tendency to slide. This is the some interbed that was exposed in the rock quarry at mile 108.4. The columnar basalt is the some flow that we sow in that quarry.

1.0

111.2 On the right is a good exposure of Columbia River Basalt. The lower flow is scorioceous near its top. This is the red oxidized bond that shows up so well along the cliff face.

1.1

112.3 On the left are the remains of a jetty that was built out into the water to capture sand being transported by the river. This particular beach, known as the "County Line Bar", is one of the most famous salmon-fishing beaches on the lower Columbia River.

0.7

113.0 On the right is a landslide that occurred during the winter of 1970-71 in the sedimentary interbed exposed at 108.4 and 110.2. The slide is full of carbonized wood which is now obscured by reclamation work done by the Highway Department to restore the hillside to a natural contour. The slide occurred during a time of high rainfall when, apparently, the weathered material derived from the interbed become saturated with water and could no longer support itself. As a result, it collapsed and as a mudflow moved over the cliff face, the rood, and down the hill. Notice that many of the rood cuts for the next few miles expose sandstone. This is material that was derived from the sedimentary interbeds upslope.

2.5

115.5 On the right is a massive sandstone interbed in the basalt. Notice the abundant cross-beds.

1.6

117.1 Columbia River Basalt flow on the right overlying a sedimentary interbed. The bed apparently was channeled, or there is a small fold axis here.

0.3

117.4 The sedimentary interbed is exposed on the right. It is a medium-grained cross-bedded sandstone.

0.8

118.2 STOP 1-8: Park on left in the turnout. A sedimentary interbed of cross-bedded arkosic and lithic sandstone is well exposed on the right. The contact with the basalt is sharply defined and easily seen.

2.1

120.3 Reddish sedimentary interbeds in the basalt on the right. No fossils have been found in these beds.

2.0

122.3 Turn left to the town of Cathlamet on Main Street. Proceed back through Cathlamet to the Puget Island ferry.

0.3

122.6 Columbia River basalt outcrops on the left.

0.7

123.3 End of bridge over the Columbia River. Road is on top of dike along the bank of the Columbia River. During times of high water the elevation of the surface of the Columbia River is higher than the elevation of Puget Island.

2.8

126.1 Puget Island ferry landing. Ferry landing, Westport, Oregon. Road is constructed on lowlands composed of tidal flat and stream sediments for next 2.0 miles.

0.4

126.5 Intersection with U.S. Highway 30. Turn right toward Astoria. Bridge over Plympton Creek. Forested bluffs on left side of road are late Oligocene sandstones. Fossils of Pittsburg Bluff and Blakeley age (Warren and others, 1945) have been collected nearby.

1.7

128.2 U.S. 30 cuts through a vesicular Columbia River Basalt flow with an oxidized rubble zone and pockets of sedimentary interbeds at west end of exposure.

0.4

128.6 Underpass, Wauna road. Wauna is the site of a large Crown Zellerbach pulp mill.

1.4

130.0 Road climbs scarp composed of Columbia River Basalt flows and arkosic sandstone interbeds. Lowry and Baldwin (1952) suggested that these interbeds represent the interfingering of the upper sandstones of the Astoria Formation with the Columbia River Basalt. Basalt flow at top of scarp dips 5° to the northwest.

1.2

131.2 Summit Clatsop Crest. Elevation 656 feet.

0.3

131.5 In road cut, uppermost flow of Columbia River Basalt in the scarp is overlain by non-marine middle Miocene-early Pliocene(?) sandstones at Clifton.

0.4

131.9 Friable, yellowish-orange middle Miocene-Pliocene non-marine sandstone in road cuts next 2.3 miles.

1.5

133.4 Bridge over Gnat Creek. Gnat Creek Fish Hatchery to left.

1.0

134.4 Intersection with gravel road to Gnat Creek Forest Park. Turn right into park.

0.1

134.5 In road cut on right, stream-terrace gravels unconformably overlie middle Miocene-Pliocene (?) sandstone.

0.2

134.7 Park in large gravel lot near restrooms.

STOP 1-9: Walk approximately 150 feet along road to the left to first road cut in middle Miocene-Pliocene (?) non-marine sedimentary rocks (at Clifton). Very coarse-grained, poorly sorted, friable, arkosic sandstone is iron-stained yellow-orange. Large angular blocks of laminated gray muddy siltstone incorporated in the sandstone are locally abundant. The siltstone is carbonaceous and micaceous.

In the next exposure along road, mudstone clasts are concentrated along bedding planes and show a southwesterly imbrication. The outline of a large channel of arkosic sandstone can be seen truncating beds of sandstone and mudstone clasts. The mudstone clasts may be penecontemporaneous "rip-ups" or slump blocks of undercut mud banks. Channels suggest a fluvial origin (ancestral Columbia River?) for the middle Miocene-Pliocene sandstone.

At other localities, the sandstone is cross-bedded and contains 20-foot thick interbeds of laminated mudstone.

Return to U.S. 30.

0.3

135.0 Intersection with U.S. 30. Reddish iron-stained stream-terrace gravels and muds exposed in road cut across the highway. Turn right.

1.5

136.5 Series of large road cuts in buff, friable, micaceous middle Miocene-Pliocene sandstone with thick overlying siltstone interbed near top of road cuts next 1.5 miles.

1.5

138.0 Middle Miocene basaltic flow breccia which underlies the middle Miocene-Pliocene sandstone exposed in road cut on left.

0.2

138.2 Road constructed on stream terrace.

0.4

138.6 On skyline to left is Wickiup Mountain composed of middle Miocene basaltic flow breccias and pillow basalts equivalent in composition to the Columbia River Basalt.

0.3

138.9 Main intersection in Knappa, Oregon. Turn left.

1.1

140.0 Mudstone of Astoria Formation (?) in road cut on right.

0.1

140.1 Bridge over Big Creek.

0.4

140.5 Turn left on gravel road up Big Creek (the gravel road that is uphill from the paved road to Tillusqua Fish Hatchery).

0.3

140.8 Reddish stream-terrace gravel composed of basalt clasts in quarry on right.

0.2

141.0 Fifty-foot quarry in bedded stream-terrace gravels and sands on right. Red roofs of fish hatchery administration buildings on left.

Take road to left.

0.2

141.2 Tillusqua Fish Hatchery on left.

0.5

141.7 STOP 1-10: Quarry in middle Miocene pillow basalt overlain by a laminated mudstone interbed and basaltic breccias of Wickiup Mountain (Figure 6). The sequence is offset by a high-angle reverse fault. Pillow rims and breccia fragments are composed of dark basaltic glass (sideromelane and tachylite). Some glass has been altered by hydration to yellowish-brown palagonite. Fragments of isolated pillows occur in the breccia.

Figure 6. Stop 10, quarry along Big Creek. Pillow basalt with overlying mudstone and basaltic breccia dipping to the left.

Snavely and others (1973) interpreted the pillow lava and breccias of Big Creek as the westward extension of plateau-derived Columbia River Basalt (Yakima type) which flowed into an embayment of the middle Miocene sea.

Return to U.S. 30.

2.8

144.5 Intersection with U.S. 30. Turn left.

0.6

145.1 Bridge over Big Creek. Valley floor composed of silty clays and terrace gravels.

1.4

146.5 Friable middle Miocene-Pliocene non-marine sandstone in road cut at crest of hill.

2.8

149.3 Intersection with road to Burnside. Remain on U.S. 30.

0.3

149.6 Dark Astoria mudstones exposed in road cut on left side of road. Note slump scars and hummocky landslide topography. Road cuts have been cut back in steps in an attempt to prevent further sliding. Mudstone next 3.7 miles.

0.6

150.2 Tidal flat on right.

0.8

151.0 Landslide area next 1.4 miles.

0.6

151.6 Active landslide scarp on upper slopes on left for next 0.2 mile. Highway skirts around recent landslide.

1.8

153.4 Bridge over John Day River.

1.9

155.3 Sandstone of Astoria Formation in road cut on left.

0.7

156.0 In road cut on right is Astoria mudstone which weathers to small crumbly, dull reddish-purple chips. Saucesian age foraminifera collected in this mudstone indicate cold, deep water (upper to middle bathyal) depositional conditions.

0.4

156.4 Sign, entering city of Astoria. Follow U.S. 30 west through town.

0.5

156.9 Houses on lower bench on right are built on fill.

0.2

157.1 Houses at road level have foundations cut into Astoria mudstone.

0.6

157.7 Bedded Astoria mudstone in road cut on left.

1.0

158.7 Astoria Column on crest of hill on left. Columbia River on right.

0.1

158.8 Ridge on left and straight ahead is predominantly middle Miocene Astoria shales. The city is plagued by frequent sliding along this ridge. Road is constructed predominantly on fill which, along the waterfront, covers the original collecting sites of the type Astoria Formation.

Astoria Columbia River toll bridge at 1 o'clock.

1.0

159.8 Road passes under toll bridge.

0.2

160.0 Turn right on Basin Street to Thunderbird Motel and the West Mooring Basin.

END OF FIRST DAY ROAD LOG

SECOND DAY

Begin mileage at intersection of Basin Street and U.S. 30 in Astoria, Oregon.

0.0 Turn left (east) onto West Marine Drive (U.S. 30) toward downtown Astoria.

0.2

0.2 Pass under Astoria Columbia River bridge.

0.1

0.3 Active slump in ridge of Astoria shales on right. Houses are built on the down-slid block.

0.7

1.0 Intersection 8th Street and Commercial Street. Turn left and proceed into right lane of Commercial Street; continue eastward to 10th Street.

0.1

1.1 Turn right on 10th and proceed up steep hill. The houses in the section of the city to the right are in an active landslide area.

0.2

1.3 Turn right onto Harrison Street.

0.1

1.4 Turn left on 9th Street and park vehicle.

STOP 2-1: Vacant lot on southwest corner of Harrison and 9th is a classic collecting locality in the type shale member of the Astoria Formation. Due to industrial expansion of the waterfront, the original collecting localities of the Astoria Formation along the banks of the Columbia River are no longer available for study. Recent construction and thick vegetative cover have obscured other localities within the city. Currently exposed at the Harrison and 9th streets locality are approximately 40 feet of crumbly dark-gray to weathered reddish-orange mudstone with some thin beds of very fine-grained sandstone and a few 1- to 2-inch beds of glauconitic sandstone. The beds dip 21° to the southwest.

Howe (1926) subdivided the Astoria Formation in the type area into a basal 150-foot-thick sandstone unit overlain by 1,000 feet or more of shale and an upper sandstone member.

The thin glauconite beds exposed at this locality are in the shale member and are approximately 250 feet above the basal sandstone.

Megafossils collected at this locality by Moore (1963) include *Dentalium pseudonyma* Pilsbry and Sharp (a scaphopod) and *Delectopecten peckhami* (Gabb).

Foraminifera from this locality are essentially the same as that described and illustrated by Cushman, Stewart, and Stewart (1947). Some of the commonly occurring species as listed by them are:

Bolivina advena Cushman
Bolivina marginata adelaidana Cushman and Kleinpell
Bulimina ovata d'Orbigny
Bulimina alligata Cushman and Laiming
Buliminella subfusiformis Cushman
Cassidulina laevigata carinata Cushman
Planulina astoriensis Cushman, Stewart, and Stewart
Plectofrondicularia miocenica Cushman
Siphogenerina branneri (Bagg)
Siphogenerina kleinpelli Cushman
Uvigerina subperegrina Cushman and Kleinpell
Valvulineria araucana (d'Orbigny)

The combination of species occurring here is generally accepted as suggesting some part of either the Saucesian or the Relizian Stages and is therefore regarded as representing part of the west-coast middle Miocene (Kleinpell, 1938).

The depositional environment suggested by foraminifera from these rocks is that of substantial depths, probably no less than an upper part of the bathyal zone, most likely something greater than 1,000 feet of depth.

Return to vehicle and proceed up 9th Street.

0.1

1.5 Turn left on Jerome Avenue.

0.3

1.8 Turn right on 15th Street and proceed up hill.

0.1

1.9 Small exposure of Astoria shale member at corner on left.

0.1

2.0 Turn left on Coxcomb Drive (Madison Avenue) toward Astoria Column.

0.8

2.8 Park in parking lot.

STOP 2-2: Assemble at bronze map on pedestal near the base of Astoria Column. Coxcomb Hill is composed of a middle Miocene sill of Depoe Bay Basalt. The sill intrudes the shale member of the Astoria Formation. From this point on a clear day you have a magnificent panoramic view of the surrounding countryside and geology (see geologic map, Figure 7).

Beginning in the north is the Columbia River spanned by the toll bridge at Astoria, which was completed in 1967. The high hills on the far side of the river are Scarboro Hills (composed of upper Eocene volcanics) with Bear River Ridge in the distance, a Miocene basaltic intrusive in Oligocene marine sedimentary rocks. To the west on the Oregon side of the Columbia is Clatsop Spit composed of elongate north-south beach ridges, beach sands, and peat bogs. On the Washington side of the Columbia, Peacock Spit and Cape Disappointment extend southward into the mouth of the river. The low ridge due west of Astoria Column upon which the city of Astoria is built is composed of Miocene Astoria mudstone and a small Tertiary intrusive overlain by the early Pliocene Troutdale Formation (quartz and chert gravels).

At the southwest end of Clatsop Spit and Plains in the far distance is Tillamook Head (a middle Miocene sill intruding Astoria age mudstones and interbedded sandstones).

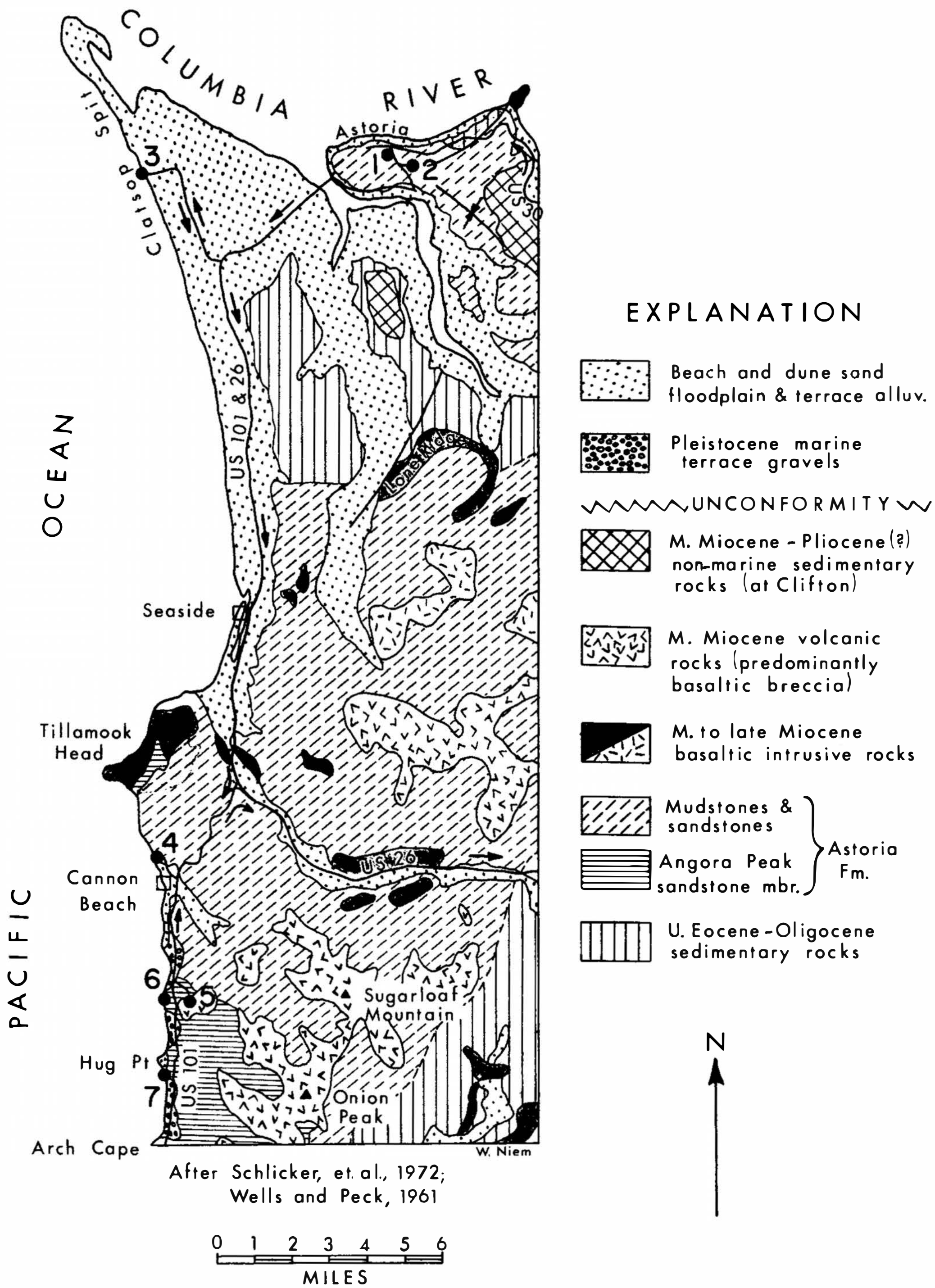


Figure 7. Geologic map of the northwest Oregon coast.

The low ragged ridges just east of Tillamook Head are composed of complexes of small dikes and ring-like dikes intruding Astoria-age sedimentary rocks.

In the foreground to the south, tidal-flat sediments along the Lewis and Clark and Youngs Rivers surround low hills of upper Eocene to Oligocene sedimentary rocks. Looking south along Youngs River, the middle ridge behind the low hills is Lone Ridge, a middle Miocene ring-like dike of Cape Foulweather Basalt. Behind Lone Ridge, the higher nearly flat-topped Eels Ridge is composed of complexes of small dikes intruding sedimentary rocks. The very distant highest hills are composed predominantly of basaltic breccias and pillow basalts as at Sugarloaf Mountain or Onion Peak.

To the southeast, the high rugged knobby peaks in the distance are Saddle Mountain and Humbug Mountain (middle Miocene basaltic breccia volcanic centers). Green Mountain, in front of Saddle Mountain, is a Miocene sill. To the east-southeast is Wickiup Mountain composed of resistant Miocene basaltic breccias.

Astoria Column, erected in 1926, rises 125 feet into the air. An interior stairway with 166 steps provides dizzy access to the narrow observation deck at the top. A pictorial history of Oregon is painted around the girth of the column. Astoria is the site of the oldest settlement in Oregon. The Lewis and Clark expedition spent the winter of 1805-06 along the river that now bears their names. In 1811 Astoria became a main depot for John Jacob Astor's Pacific Fur Company.

Complete Coxcomb Hill loop and descent hill. Return to 15th Street.

0.8

3.6 Intersection Coxcomb Drive and 15th Street. Turn left on 15th Street.

0.1

3.7 Turn left on Niagara Avenue. Recent slumping displaced Niagara Avenue.

0.1

3.8 Turn right on 16th Street (Williamsport Road).

0.7

4.5 City of Astoria sanitary landfill site on left. Road cut exposure below powerline exposes upper sandstone member of Astoria Formation which lies close to the contact with the underlying middle Astoria shale member.

0.3

4.8 Intersection Williamsport Road with State Highway 202. Turn right on Highway 202 toward Astoria. Youngs Bay on left.

0.8

5.6 On right in bluff behind Highway Department facilities, thick arkosic sandstone interbed in shales of the Astoria Formation. The exposure was included in the "upper" sandstone by Howe (1926), but its actual stratigraphic position remains unclear.

0.3

5.9 Stop sign. Go straight.

0.1

6.0 Intersection with road to Youngs River Loop and Lewis and Clark River. Go straight.

0.6

6.6 Astoria High School on right. Ridge behind school is composed of Astoria shale.

0.7

7.3 Intersection with U.S. 101 and 26. Bear left to cross bridge over Youngs Bay toward Warrenton and Seaside.

2.3

9.6 Railroad crossing. Intersection, continue on U.S. 101 and 26 toward Seaside and Tillamook. Road built over tidal-flat sediments.

0.6

10.2 Intersection with road to Ft. Clatsop National Memorial. Go straight. Lewis and Clark spent the winter of 1805-06 at Ft. Clatsop.

1.2

11.4 Bridge over Skipanon River.

0.4

11.8 After railroad crossing, turn right on Ridge Road toward Fort Stevens State Park.

0.3

12.1 Sand pit in beach ridge on left. Ocean View Cemetery built on beach ridge on right, one of several beach ridges of Clatsop Plains.

0.2

12.3 Swale between beach ridges occupied by elongate Smith Lake on left.

0.4

12.7 Intersection, continue straight ahead. Road climbs up on a beach ridge and parallels beach ridges on both sides of the road.

0.9

13.6 Sand pit in beach ridge on left exposes cross-bedded sand.

1.6

15.2 Turn left into Fort Stevens State Park and follow signs to beach. The park and old fort were named for General Isaac Stevens, a hero of the Civil War who died in 1862. He was the first governor of Washington Territory. This area containing some 3,000 acres of sand is called the Clatsop sand plains. Much of the dunes were stabilized in the 1930's by planting beach grass, shrubs, and trees.

The road crosses six to seven 25- to 30-foot-high beach ridges before it reaches the beach.

0.4

15.6 Stop sign, proceed ahead.

0.2

15.8 Cross beach ridge and stay on main road. Note Coffenbury Lake on the left occupies a swale between beach ridges.

0.7

16.5 Park in parking lot. Modern restroom facilities are available here.

STOP 2-3: Walk to the beach and turn right (north). Clatsop sand plains consist of a 19 mile-long coastal plain of beach sands, beach ridges, and intervening swales with peat, lake, and tidal-flat sediments. The plains stretch from Seaside in the south to Hammond in the north and range from $\frac{1}{2}$ mile to 2 miles in width. Clatsop Spit at the north end of the Clatsop sand plains extends $2\frac{1}{2}$ miles in a northwesterly arc into the mouth of the Columbia River.

The wreck of the Peter Iredale is partly buried in the beach. This British ship was shipwrecked in the early 1900's. All hands were rescued.

The beach ridge to the right is being undercut by winter storm waves. The beach slopes approximately 2° seaward. Note the rich black sands of the winter beach. These heavy mineral sands are fine-grained, well-sorted, and angular to sub-rounded. The composition of the sands is predominantly quartz, magnetite, ilmenite, and amphiboles with subordinate amounts of plagioclase, olivine, tourmaline, volcanic glass, basaltic rock fragments, and trace amounts of hematite, garnet, rutile, epidote, apatite, zircon, and biotite. The percentage of opaque heavy minerals ranges from 30 percent to 85 percent. The mineral composition of the sands suggests a predominantly basaltic source with detritus also from recycled quartz sandstones and/or an acid igneous source transported via the Columbia River. The black sands here are at least 3 feet thick and constitute a potential future ore for iron and titanium. Twenhofel (1946) estimated that 15,000 to 30,000 yards of sand containing 15 percent ilmenite occur on Clatsop Spit near the mouth of the Columbia River. J.E. Allen, Portland State University, (in an unpublished report to the Department of Geology and Mineral Industries, 1941) outlined an area of black sand 300 feet wide by 800 feet long in the town of Hammond on Clatsop Spit 2 miles east of Fort Stevens State Park. The lens of black sand is 3 to 4 feet thick and is composed of 30 to 81 percent magnetite and ilmenite.

The dominant stratification is parallel lamination in the beach cross section and large-scale planar cross-lamination in the beach ridge. The lamination is accentuated by dark laminae of magnetite, ilmenite, and amphibole mineral-rich layers alternating with light-colored quartz/feldspar-rich layers. Grass roots have locally destroyed the stratification in the beach ridge.

Return to U.S. 101 and 26.

3.9

20.4 "Y" in road, go left off beach ridge.

0.8

21.2 Intersection, turn right on U.S. 101 and 26 toward Seaside. For the next 12 miles the road is constructed on the Clatsop sand plains and parallels several elongate north-south beach ridges.

0.6

21.8 Peat bogs in swale on left. Swan Lake on right. U.S. 101 and 26 constructed on beach ridge with swales on either side for next 1.4 miles.

1.4

23.2 Small oblique dunes on right. Sand pit in beach ridge on left.

0.6

23.8 Tree-covered hills parallel to road on left are upper Eocene to Oligocene sedimentary rocks. Lake and peat swamp in swale on right.

0.5

24.3 On right, Astoria Golf and Country Club built on beach ridge. Road on a parallel beach ridge with a lake and peat swamp between. Eight to nine elongate beach ridges lie between the road and the beach here. Rows of beach ridges parallel the north-south coastline of the Clatsop Plains and can be traced on aerial photographs for almost the entire length of the plains. Cooper (1958) postulated that the formation of the beach ridges of the Clatsop Plains was initiated during pauses in seaward beach accretion when submarine sand bars continued to grow in size and emerged as new beaches. The ridge developed from storm berms behind the emergent beach and by entrapment of dune sand and stabilization by grass. The beach accretes further seaward to form additional beach ridges.

0.3

24.6 Sand pit on right.

1.3

25.9 Well-developed beach ridges on right with a small elongate lake in the swale between.

0.3

26.2 Highway crosses elongate lake. Peat and silty clays in low areas on left.

0.7

26.9 Sugarloaf Mountain at 12 o'clock.

2.9

29.8 Sign, entering the town of Gearhart. Peaks at 12 o'clock are Onion Peak and Sugarloaf Mountain predominantly composed of resistant middle Miocene basaltic breccia and pillow basalts.

0.4

30.2 Intersection, road to Gearhart city center and U.S. 101. Remain on U.S. 101.

1.1

31.3 Bridge over Neawanna Creek.

0.1

31.4 Railroad crossing. At 12 o'clock is Tillamook Head, a middle Miocene basaltic sill. Hills on left are composed of Astoria Formation.

1.2

32.6 The city of Seaside is built on beach and dune sands and gravels.

0.1
32.7 Street to Seaside city center to right. Remain on U.S. 101.
0.1
32.8 Twin peaks at 10 o'clock are a middle Miocene basaltic intrusive.
1.1
33.9 Highway is constructed on beach gravels. These basalt gravels, in part derived from Tillamook Head, have diverted the mouth of Necanicum River 3 miles northward by longshore drift.
0.1
34.0 Necanicum River stream gravels underlie the flat valley floor on the right.
1.7
35.7 Quarry in middle Miocene basaltic sill with blocky fracture pattern on the left.
0.1
35.8 Bridge over Necanicum River.
0.1
35.9 Quarry at 3 o'clock in basaltic sill, may be the east end of the Tillamook Head sill.
0.3
36.2 Quarry in sill on left. Saddle Mountain at 12 o'clock.
0.6
36.8 Intersection U.S. 101 and U.S. 26 (Cannon Beach Junction). Go right on U.S. 101 toward Tillamook.
1.7
38.5 In road cut on left, basal contact of basaltic sill with underlying mudstones. Mudstone is at road level.
0.6
39.1 Sill exposed in deep road cut on both sides of the road. Northern end of the road cut exposed columnar-jointed basalt sill. At least two oblique faults at the southern end of this cut place sill against Astoria mudstones. Mudstones are stained orange with iron.
0.9
40.0 Road cut in orange-stained Astoria mudstones with intercalated thin sandstones intruded by an irregular dike of middle Miocene basalt. Saucesian age foraminifera were collected from the mudstone.
0.1
40.1 Intersection, U.S. 101 and beach loop. Go right toward Cannon Beach. Haystack Rock at 12 o'clock.
0.3
40.4 Intersection, go right toward Ecola State Park.
0.2
40.6 Intersection, turn right toward Ecola State Park and Indian Beach.
0.2
40.8 Road climbs hill of Astoria mudstones and sandstones.
0.5
41.3 Entrance gate to Ecola State Park. (Note: this gate is locked at 4:30 pm during the winter months: at 7:30 pm during summer.)
0.6
41.9 In road cut on right, yellowish-orange silty mudstone intruded by small basaltic dikes.
0.2
42.1 Irregular road surface due to landsliding.
0.2
42.3 Intersection, go left to parking lot.
0.2
42.5 STOP 2-4: Ecola State Park. Parking lot is in the midst of an active landslide area. Ecola State Park is underlain by a complex of sills and dikes in a turbidite sandstone

and mudstone facies of the Astoria Formation. Uphill from the parking lot is a 75-foot scarp of a landslide that occurred in 1961. The previous parking lot was destroyed beyond repair and was replaced by the present lot. Slabs of pavement of the former parking lot are visible in the brush and tall grass along the creek west of the restrooms. The slide produced a hummocky surface that was leveled off for the present parking lot.

Take the path to the viewpoint on the small forested point to the west (Ecola Point). At the viewpoint to the north in the foreground, the toe of the 1961 slump is being undercut by wave action. Wave action is destroying the support of the hill and may cause further sliding. Knob to the north is composed of alternating beds of middle Miocene mudstones, sandstones, and thin sills dipping steeply to the east.

The third cove to the north is Indian Beach. Slumping has tilted many trees on the south part of the cove. Beyond is Bald Mountain (south part of the Tillamook headland) held up by the south end of the Tillamook sill that dips to the southeast.

To the northwest the lighthouse is built on Tillamook Rock, a remnant (stack) of the sill. Boulders hurled up by winter storm waves have broken the lighthouse beacon at the top (139 feet above sea level) several times. A heavy steel grating now protects the beacon. On one occasion, a 135-pound rock sailed to the 91-foot level and landed in the keeper's house.

To the south the high irregular peaks include Onion Peak, unnamed peaks, and Angora Peak which are composed of predominantly middle Miocene basaltic breccias and which probably constitute the remnants of a local eruptive center (Figures 7 and 8). The low hills behind the town of Cannon Beach are composed of Astoria sandstone (Angora Peak sandstone member) that underlies the basaltic breccia of Onion Peak and Angora Peak. The farthest headlands visible are Neahkahnie Mountain (a middle Miocene sill) and the sill at Oswald West State Park. In the distance the highest stack with several small stacks around it is called Haystack Rock. The twinned peaks southeast of Haystack Rock and behind the village of Tolovana Park are Double Peak (Miocene basaltic breccia).

Stacks within the park, including Sea Lion Rock (with the sea arch) to the west, are remnants of the sill, related dikes, and overlying contorted sedimentary rocks.

Return toward parking lot and take path to the right to Crescent Beach. Note the numberous landslide scarps. A midden moundalso occurs along the trail.

Assemble at the south end of the cove. Chevron folds of alternating beds of sandstone and mudstone are well exposed in the sea cliff here (Figure 9). Two- to six-inch-thick, medium-gray Astoria-age mudstones alternate rhythmically with 3- to 6-inch fine-grained laminated sandstones. The feldspathic sandstones contain mica. Sedimentary structures in these sandstones include carbonaceous laminae, micro cross-laminations, graded bedding, load structures, and convolute bedding (best displayed in sea cliffs at north end of the cove). The sandstones appear to be turbidites with the a, b, and c divisions of the Bouma sequence.

Preliminary studies of limited foraminiferal collections from this locality suggest that they are very similar to those assemblages known from the Astoria Formation in the town of Astoria. The following are a few of the more commonly occurring forms:

- *Bolivina* cf. *B. advena* Cushman
- *Bulimina alligata* Cushman and Laiming
- *Buliminella subfusiformis* Cushman
- *Dentalina* spp.
- *Globigerina* spp.
- *Nonionella miocenica* Cushman
- *Siphogenerina branneri* (Bagg)
- *Valvulineria araucana* (d'Orbigny)
- *Virgulina* cf. *V. californiensis* Cushman

Figure 8. View from Ecola Point (Ecola State Park) looking southeast. Far distant peaks are remnants of middle Miocene submarine basaltic breccia eruptive centers overlying lower forested slopes of Astoria sandstone and mudstones. Stacks in foreground are remnants of middle Miocene basaltic sill intruded into the Astoria Formation.

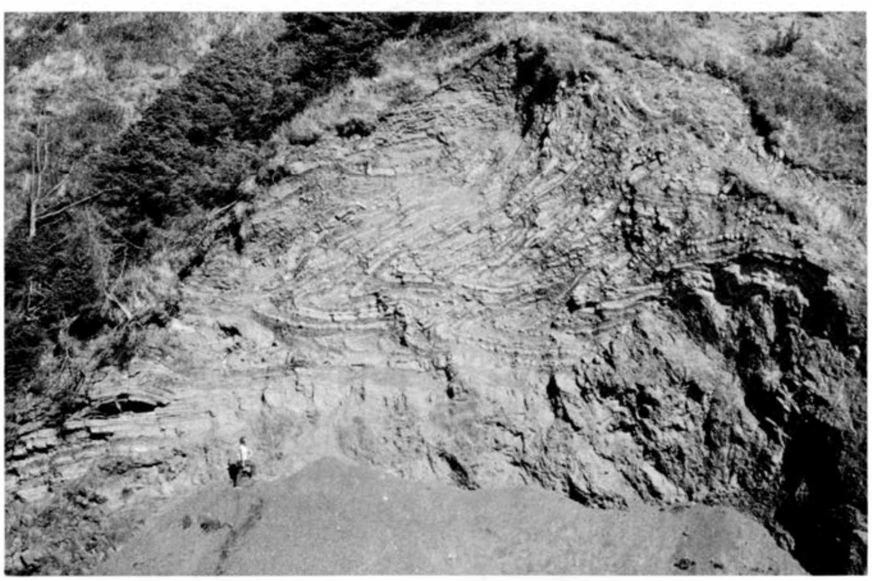


Figure 9. Chevron folded rhythmically bedded sandstones and mudstones of Astoria Formation associated with basaltic sills and dikes. Deformation was probably penecontemporaneous with deposition. North end of Crescent Beach, Ecola State Park.

This assemblage suggests a position in either the Saucesian or Relizian Stage and therefore represents a lower to middle part of the west coast Miocene. The assemblage further suggests an outer neritic to upper bathyal depositional environment, possibly at a depth of 500 to 1,500 feet in cool water.

These folded sedimentary units are intruded by a sill of Depoe Bay Basalt with many dike-like apophyses. The contact between the intrusive and the sedimentary rocks is sharp. However, locally the intrusive is brecciated and altered to greenish clay and contains large blocks of contorted strata. A sample of the intrusive at Indian Beach was potassium-argon dated by Don Parker, graduate student at Oregon State University, as 15.9 $\pm$ 0.4 m.y. The sedimentary units are slightly older (lower to middle Miocene). An interpretation of the features observed here is that the strata were only semi-lithified sediments and deformed when they were intruded. The igneous material fragmented as it came into contact with the wet sediments.

Many basalt cobbles on the beach contain large yellowish plagioclase phenocrysts characteristic of middle Miocene Cape Foulweather Basalt. These cobbles were derived from nearby dikes. The Cape Foulweather Basalt is younger than the Depoe Bay Basalt and is thought to be equivalent to the late-Yakima Basalt in eastern Oregon.

Return to the parking lot. On the return trip up the path note similarly deformed sediments along the top of the sill on the south side of Ecola Point. A good viewpoint is just above the midden mound.

Return to Cannon Beach loop (2.0 miles).

2.0

44.5 Intersection with Cannon Beach loop. Turn right.

0.1

44.6 Bridge over Elk Creek. Elk Creek or Ecola is the southwesternmost point reached by members of the Lewis and Clark expedition when they came to this area on January 8, 1806, to trade for whale blubber and oil from the "Killamuck" Indians.

0.4

45.0 Clear-cut peak at 10 o'clock is Sugarloaf Mountain.

0.1

45.1 Road climbs up on a Quaternary marine terrace.

1.0

46.1 Wide shoulder on right provides a pull-off and viewpoint of Haystack Rock at 4 o'clock. Haystack Rock is a stack composed of middle Miocene basaltic breccia, pillow basalts, and dikes. The surrounding smaller stacks are called the Needles. Near the base of Haystack Rock the breccias are in contact with the underlying steeply seaward dipping burrowed siltstone, fine-grained sandstone, and mudstones of the Astoria Formation. The contact can be studied at low tide.

0.6

46.7 The village of Tolovana Park is built on a marine terrace. Tolovana Park post office.

0.2

46.9 Intersection, turn left to U.S. 101.
Turn right toward Manzanita and Tillamook. Double Peak at 11 o'clock.

0.7

47.6 Turn left on gravel road (Tolovana Mainline) up hill.

0.5

48.1 Junction, go left.

0.2

48.3 Junction, go right up hill. Basalt dikes cutting Astoria sandstones and mudstones in road cut on right.

0.1

48.4 Junction, go straight ahead. Approximate contact of basaltic breccia and underlying Astoria sandstone. Gravel road parallels the west fork of Elk Creek. Basaltic breccia exposed in road cuts and cliffs on right for next 0.5 mile.

0.5

48.9 STOP 2-5: Pull off to the side of the gravel road. The west fork of Elk Creek cuts a gap through the two peaks of Double Peak. Basaltic breccia is exposed in the deep road cut here. On fresh surfaces poorly sorted angular fragments (one-eighth inch to eight inches) of dark aphanitic basalt and basaltic glass are in a groundmass of dark yellowish-brown palagonite and basaltic glass (sideromelane and tachylite). Some basalt fragments contain zeolite-filled amygdules. Thin veinlets of zeolites cut the breccia. More than 2,000 feet of middle Miocene submarine extrusions of basalt breccia, isolated pillow basalts, pillow flows, and rare subaerial flows, and feeder dikes form the high bald rugged mountains in this area such as Saddle Mountain, Onion Peak, and Angora Peak which are thought to be erosional remnants of submarine basaltic eruptive centers. The basalt breccias are stratigraphically equivalent to the middle Miocene Depoe Bay Basalt of the central Coast Range and are compositional equivalents of the Yakima Basalt of the Columbia River Group in the Kelso-Cathlamet area of Washington (Snavely and others 1973).

Proceed another 0.3 mile farther along the gravel road to a wide turn-around on the left at a curve in the road. Return to U.S. 101.

2.1

51.0 Intersection, U.S. 101 and Tolovana Mainline. Turn left on U.S. 101.

0.6

51.6 Pull off into second viewpoint parking lot on right.

STOP 2-6: Silver Point. Stacks at Silver Point west of the first parking lot are composed of a basaltic sill. Deep highway cut on east side in upper part of Angora Peak sandstone member (informal) of the Astoria Formation. Thick interbeds of light-gray laminated sandstone and medium-gray silty mudstones. Large recent landslide in center of road cut illustrates a common problem in the fine-grained portion of this member. Sandstones are fine- to very fine-grained, micaceous and contain abundant carbonaceous plant matter in the dark laminae. A broad mudstone-filled channel truncates the wedge-shaped sandstones. Convolute bedding, micro cross-lamination, and load and flame structures occur in the sandstone beds. About 200 feet above this exposure are the basaltic breccias of Double Peak.

With CAUTION, especially after a rain, follow the path down the slumped pavement of the old highway to the beach. The sea cliff directly below the parking lot is a large slump block composed of a 6- to 8-foot-thick 50-foot-wide lens of sandstone in this fine-grained sequence (Figure 10). In the sea cliff to the north, a conglomerate-filled channel is intruded by a basaltic sill. The carbonate-cemented conglomerate contains pebbles of basalt, sandstone, quartz, pumice, agate, and large blocks of laminated mudstone. Lenses of sandstone in the conglomerate contain well-developed micro trough cross-bedding. Load and flame structures occur in the mudstones and siltstones at the base of the conglomerate.

This sequence is interpreted to have been deposited in a deltaic environment. The conglomerate and sandstone channel and lenses become the dominant lithologies half a mile south of this exposure; the mudstones become subordinate. Near Angora Peak to the southeast, coal beds, burrowed siltstones, large-scale planar cross-bedded and channeled sandstones, and conglomerate compose a 1,000-foot section of this sandstone member of the Astoria Formation between the overlying middle Miocene basaltic breccia of Angora Peak and the underlying late Oligocene mudstone.

0.1

51.7 In the spring of 1972, U.S. 101 for the next 0.2 mile dropped 3 to 6 inches due to slumping in the fine-grained Astoria sandstone.

0.4

52.1 In road cut on both sides of road, dikes through soft sediment deformed the laminated buff sandstones. Large contorted, penecontemporaneously deformed blocks of this sandstone occur in a pebbly sand matrix in the sea-cliff exposure of this ridge.

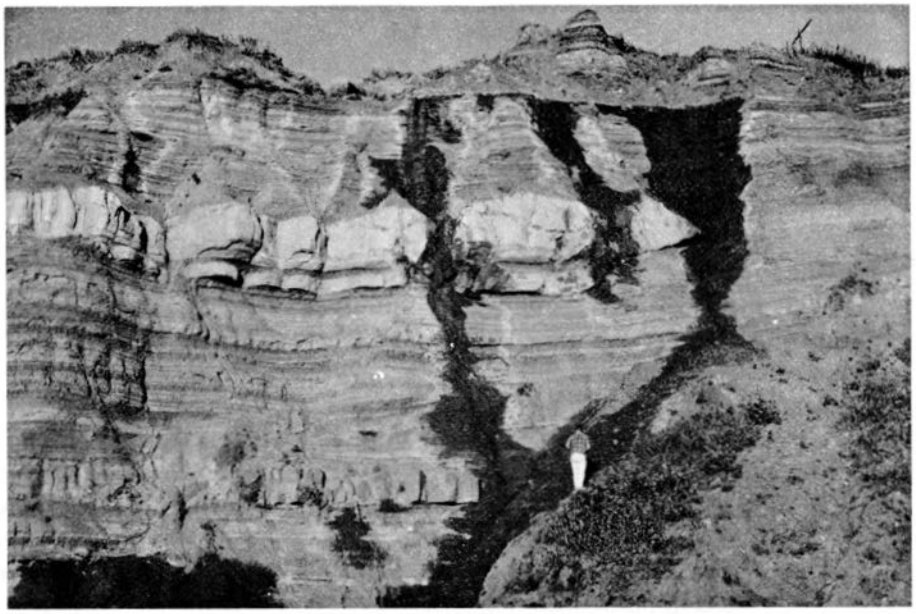


Figure 10. Thick lens-shaped sandstone in interbedded sandstones, carbonaceous siltstones, and mudstones of Angora Peak sandstone member of Astoria Formation. Sea cliff below viewpoint, Silver Point, on U.S. 101.

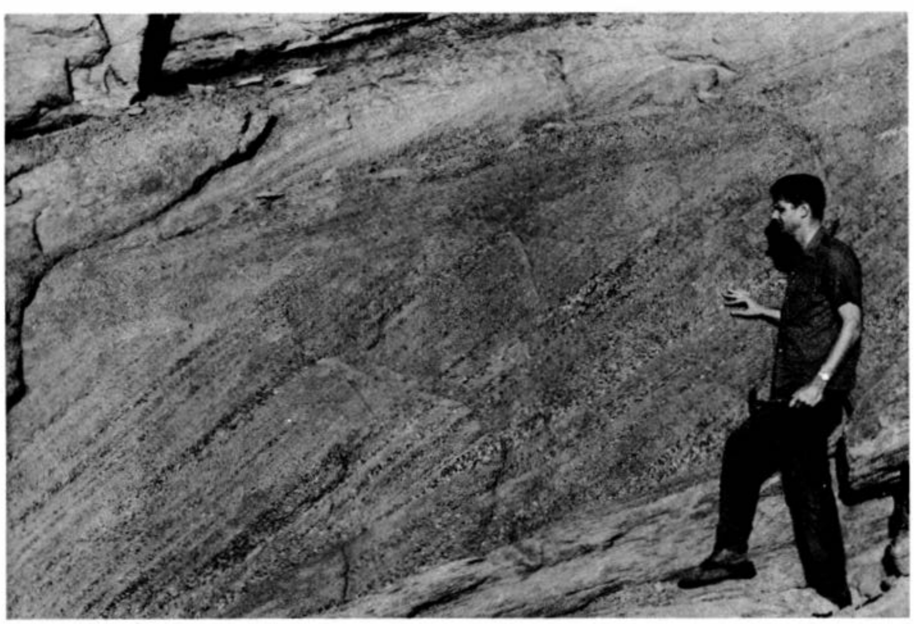


Figure 11. Large-scale planar cross-bedded conglomeratic sandstone in Angora Peak sandstone member of the Astoria Formation. Master stratification is inclined to the left. South side of Austin Point.

1.2

53.3 In next several road cuts, buff coarse-grained Astoria sandstones with minor medium-gray mudstones are steeply dipping and are cut by several basaltic dikes.

0.3

53.6 Intersection, turn right into Hug Point State Park.

0.1

53.7 Park in parking lot.

STOP 2-7: Hug Point State Park. Take path to beach and turn left (south). Low cliff of Quaternary marine terrace gravel and sands (iron-stained) are exposed along the beach. The first small headland consists of an east-west striking basaltic dike that cuts across steeply dipping (southeastward) cross-bedded sandstones and conglomerates of the Astoria Formation (not accessible during high tide).

Around the headland is a small cove which is the center of the axis of a syncline that plunges seaward. The small headland (Austin Point) at the south end of the cove contains a small basaltic sill and dike intruded into steeply dipping (northwestward) cross-bedded sandstones and conglomerates. Go around the Austin Point headland to the south side where poorly sorted, conglomeratic, and cross-bedded dusky-yellow sandstones (Figure 11) of the Astoria Formation (Angara Peak sandstone member) are exposed.

Subangular to well-rounded clasts (up to 2 inches in length) include mostly pumice, basalt, quartz, mudstone, volcanic rock fragments, and minor agate and welded tuff. Probable source rocks are the ancestral Cascades and Eocene Coast Range volcanics and sedimentary rocks. Individual cross-beds are graded, and the whole set is graded. Sandstones are medium- to very coarse-grained and fairly well sorted. Climbing ripples are abundant in a two-foot medium-grained sandstone bed. Paleocurrent measurements show a northwestward current dispersal. Same thin laminated siltstone interbeds contain carbonaceous laminations. Tree limbs as long as $1\frac{1}{2}$ feet occur in the interbeds. Return to path to parking lot.

From the path walk approximately $\frac{1}{4}$ mile north to the third cove (access only during low tide) past the waterfalls and over the old wagon road carved into the headland. Several large-scale soft-sediment deformation folds in cross-bedded Astoria sandstone (Angora Peak sandstone member) trend across the beach. Large blocks of laminated siltstone are incorporated in the sandstone. Some beds of sandstone weather to a nodular popcorn-like surface.

The 100-foot-high sea cliff beyond the wagon road contains nearly vertical sandstone beds with carbonaceous laminae and intercalated thin coaly beds. The laminae are abundantly micro-faulted due to soft-sediment deformation. Thin basaltic dikes cut across the slump structures. A peperite dike with clasts of altered basaltic breccia and blocks of carbonaceous laminated silty sandstone is exposed at beach level.

0.1

53.8 Intersection. Turn right on U.S. 101.

0.3

54.1 Massive conglomeratic cross-bedded Astoria sandstone in road cuts on both sides of road dips 45° to the south.

0.1

54.2 Bridge over Fall Creek; continuation of axis of syncline observed at beach level.

0.1

54.3 Conglomeratic Astoria sandstone in road cut dips 35° to the north. A thin basaltic sill parallels the bedding.

0.2

54.5 On left, Cannon Beach historical marker. "In 1846, the 300-ton U.S. Naval Survey schooner, the Shark, was shipwrecked off the coast near this point. In an attempt to save the ship, the masts were chopped down and the cannons were jettisoned, but the ship broke up and the cannons washed ashore."

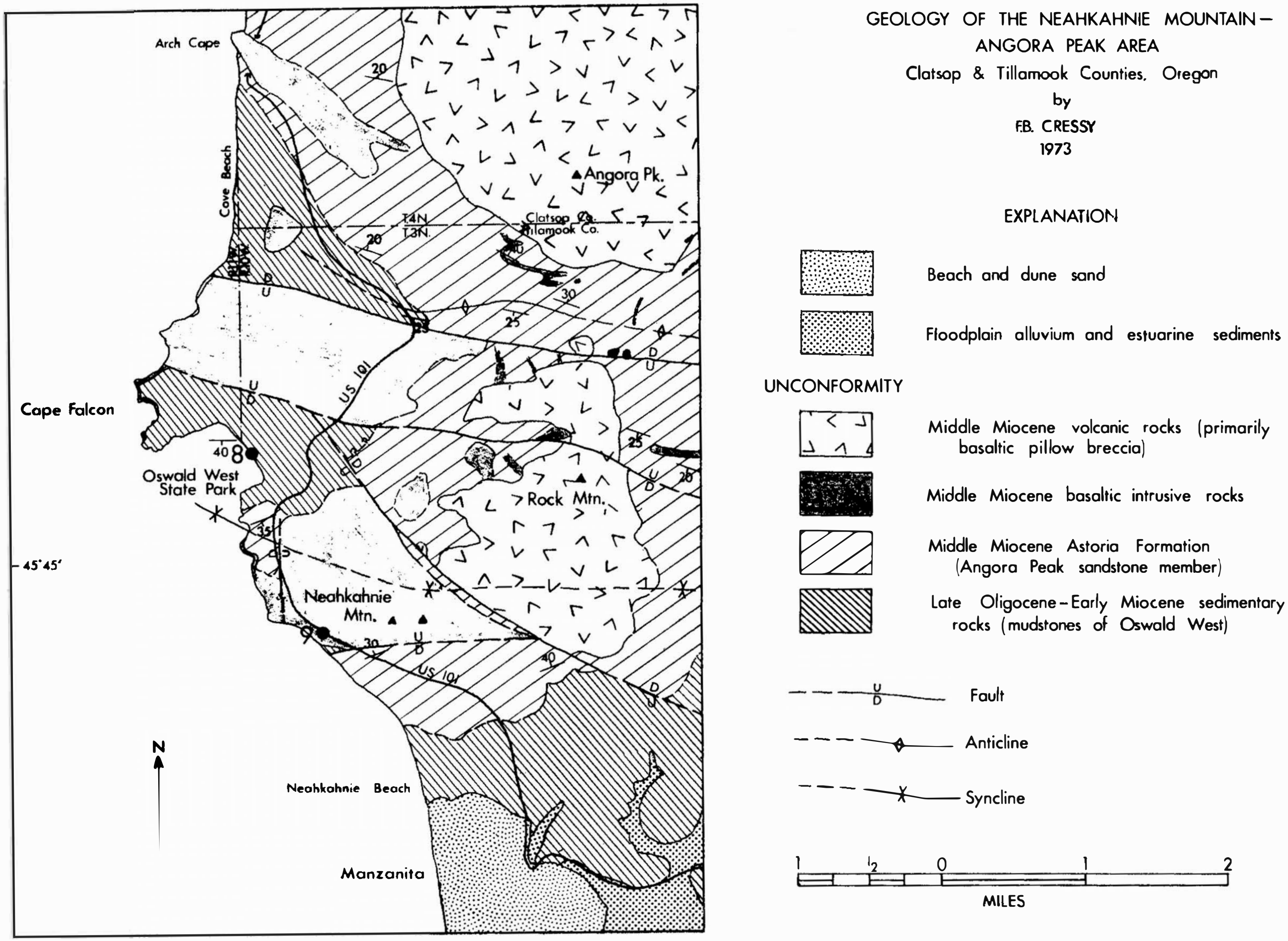

GEOLOGY OF THE NEAHKAHNIE MOUNTAIN – ANGORA PEAK AREA
Clatsop & Tillamook Counties, Oregon
by
F.B. CRESSY
1973
EXPLANATION
Beach and dune sand
Floodplain alluvium and estuarine sediments
UNCONFORMITY
Middle Miocene volcanic rocks (primarily basaltic pillow breccia)
Middle Miocene basaltic intrusive rocks
Middle Miocene Astoria Formation (Angora Peak sandstone member)
Late Oligocene-Early Miocene sedimentary rocks (mudstones of Oswald West)
Fault
Anticline
Syncline
MILES
Arch Cape
Cove Beach
Angora Pk.
T4N
T3N
Clatsop Co.
Tillamook Co.
Cape Falcon
Oswald West State Park
US 101
Rock Mtn.
45°45′
Neahkahnie Mtn.
Neahkahnie Beach
Manzanita
N

FIGURE 12

0.4

54.9 Clear-cut peaks on left are composed of Miocene basaltic breccia. Angora Peak at 10 o'clock.

0.4

55.3 Entering the village of Arch Cape, which is built on Quaternary marine terrace gravels.

0.6

55.9 North portal of tunnel carved through a basaltic dike that forms Arch Cape.(Figure 12).

0.4

56.3 Small sea stacks in water on right are Gull Rocks (remnants of basaltic dikes). At 12 o'clock is Round Mountain, a Tertiary basaltic intrusion, surrounded by low hummocky hills of late Oligocene-early Miocene mudstones of Oswald West formation (informal).

0.1

56.4 East-west ridge on right behind Round Mountain is uplifted Oswald West basaltic sill in fault contact with Astoria (?) conglomerate at water's edge. This conglomerate contains sandstone clasts up to 11 feet across.

0.7

57.1 Dark late Oligocene-early Miocene mudstones of the Oswald West formation (informal) in road cut on right with overlying colluvium.

0.3

57.4 Clatsop-Tillamook county line.

0.6

58.0 On left is clear-cut Angora Peak with barren cliffs of basaltic breccia.

0.3

58.3 Highway crosses trace of northern fault that uplifts Osward West basaltic sill. Road cuts on right for next 1.1 miles are in Osward West basaltic sill.

0.3

58.6 Sill is well-exposed in road cut on right.

0.8

59.4 Road crosses trace of southern fault (?) that uplifts Oswald West sill.

0.2

59.6 Turn left into Oswald West State Park's main parking lot. Restroom facilities available. STOP 2-8: Oswald West State Park. Proceed down path under bridge and follow signs to ocean beach (approximately ¼ mile). Go through picnic area and turn right (north) along beach. Picnic area is built on Quaternary terrace gravels. Approximately 1,500 feet of late Oligocene to early Miocene interbedded mudstones and tuffaceous siltstones of the Oswald West formation dipping 40° southward are exposed along the beach and in the sea cliffs. The strata include a few graded graywackes, convoluted beds, a submarine mudflow, and clastic dikes (Figure 13) suggestive of rapid deposition in a deep-water environment. At the north end of the cove near the waterfalls, abundant small, dark, arcuate to spiraled specimens of *Scalarituba* (fecal ribbon form) riddle the tuffaceous siltstone beds. The intricate meandering pattern of *Zoophycos* occurs on some bedding planes (Figure 14). (Joides cores in the Caribbean contained complex *Zoophycos* burrows from depths of 4,000 m.) Other trace fossils from this locality include *Scalarituba* (radical meniscate form), *Taenidium annulata*, *Planolites*, *Chondrites*, *Teichichnus*, and ?*Helminthopsis labyrinthica*. This is a deep-water assemblage of bathyal or greater depths very similar to the assemblage found in European Cretaceous and Tertiary flysch (Chamberlain, personal communication, 1972).

A limited foraminiferal assemblage was obtained approximately 20 feet above the convoluted sandstone bed. Tentative identifications of the more commonly occurring forms are listed below:

Anomalina californiensis Cushman and Hobson
Cassidulina cf. *C. crassipunctata* Cushman and Hobson
Gyroidina orbicularis planata Cushman

Figure 13. Late Oligocene thin-bedded mudstones and tuffaceous siltstones inclined to the right are cut by thin clastic dikes. Dikes also cut through a thick mudstone unit containing a heterogeneous mixture of pebbles and boulders of sandstone and siltstone (submarine mudflow). Cliff at Short Sands Beach, Oswald West State Park.

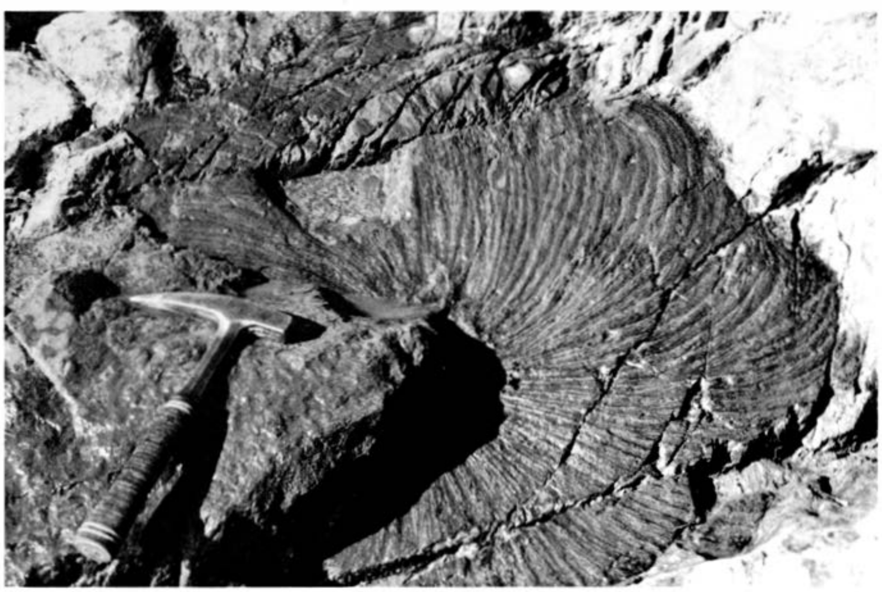


Figure 14. Bedding plane of late Oligocene mudstone contains a complex form of Zoophycos, an intricate burrow pattern that radiates from a single center. Near waterfalls north end of Short Sands Beach, Oswald West State Park.

Pseudoglandulina inflata (Bornemann)
Robulus spp.
Uvigerina cf. *U. garzaensis* Cushman and Siegfus

Preliminary studies of the assemblage suggest that it best compares with those known from the Zemorrian stage which, in the northwest at least, is generally regarded as representing the upper part of the Oligocene of this west coast area (Rau, 1966). This assemblage has strong affinities for cold water bathyal deposition somewhere below 1,000 feet of depth.

The mudstones of Oswald West are equivalent in part to the Scappoose Formation of the eastern part of the Coast Range.

Megafossils found in the mudstones at this locality by Warren and others (1945) include:

Acila gettysburgensis (Reagan)
Lima cf. *L. twinensis* Durham
Lima n. sp.
Echinophoria rex (Tegland)
E. apta (Tegland)

In the headland at the south end of the cove the mudstones of Oswald West are in contact with the light-colored Astoria sandstones and conglomerates of the Angora Peak member. The top contact of a sill dipping eastward forms the distant stack. This entire cove is criss-crossed with high angle normal and reverse faults with minor displacements.

The sea cliffs at the end of Cape Falcon expose the contact of the mudstones of Oswald West and the underlying basaltic sill. Pseudo-pahoehoe flow structures are present on top of the sill. The sill on nearby sea cliffs steps its way up the cliffs.

Return to parking lot.

Turn left (south) on U.S. 101.

0.2

59.8 Late Oligocene mudstones of Oswald West formation in road cut on left. High ridge at 12 o'clock is Neahkahnie Mountain sill.

0.3

60.1 Late Oligocene mudstones of Oswald West formation in road cut on left.

0.1

60.2 Trace of contact of Angora Peak sandstone member of Astoria Formation and underlying mudstones of Oswald West formation. The contact is well exposed in precipitous sea cliffs ¼ mile to the west.

0.3

60.5 Trace of axis of syncline, exposed in sea cliffs below, trends across highway.

0.1

60.6 Small tree-covered headland on right is part of downfaulted Neahkahnie sill. Fault (?) in hollow between road and grass-covered knob downdrops west block of sill relative to east block which forms Neahkahnie Mountain.

0.4

61.0 Jointed Neahkahnie Mountain basaltic sill exposed in road cuts on left for next 0.8 mile. Pull off onto wide viewpoint area on right.

0.1

61.1 STOP 2-9: Neahkahnie Mountain Viewpoint. The viewpoint is constructed on Neahkahnie Mountain sill. The sill is approximately 1000 feet thick, dips gently northeastward, and is composed of coarse-grained basalt or micro-gabbro. The basal contact of the sill with white to buff bedded tuff (?) occurs near the cobble beach below. The sill is strongly jointed. No evident differentiation of the sill has occurred except for development of micro-pegmatitic schlieren in some samples.

Figure 15. Air view of Saddle Mountain, a remnant of a middle Miocene eruptive center of submarine basaltic breccias and pillow lavas. Photograph by Delano Studios and Aerial Surveys.

A sample from the knob at the next viewpoint turnout was dated by Don Parker at 15.5 $\pm$ 0.4 m.y. (or middle Miocene).

To the south is Nehalem River bay mouth bar. Longshore drift of the sand has deflected the mouth of the Nehalem River southward. The villages of Manzanita and Nehalem are built on the bar. Active dunes cover parts of the bar. In the distance the tall hills are composed of Eocene Tillamook Volcanics and upper Eocene sedimentary rocks, the oldest rocks in the northern Coast Range.

0.7

61.8 In road cut on left, fault; dark basaltic sill faulted against buff Astoria sandstones.

0.1

61.9 Laminated carbonaceous Astoria sandstones in road cut on left dip northward into sill.

Turn right into observation turnout. Thin coal beds have been reported on the south side of Neahkahnie Mountain in the Angora Peak member of the Astoria Formation.

Turn around and return via U. S. 101 to the intersection of U.S. 101 and U.S. 26 at Cannon Beach Junction near Seaside (16.9 miles). Return to Portland via U.S. 26 (62.4 miles).

OPTIONAL SIDE TRIP

11.2 miles east of Cannon Beach Junction on U.S. 26 is an intersection with a road to the left to Saddle Mountain State Park (Figure 15). Saddle Mountain and Humbug Mountain are erosional remnants of middle Miocene submarine basaltic flow breccias. Round trip distance is 13.8 miles.

0.0 Junction, U.S. 26 and road to Saddle Mountain State Park, turn left.

2.6

2.6 Road cuts in basaltic intrusive in Astoria Formation.

0.3

2.9 Crest of ridge, drainage divide between Necanicum and Lewis and Clark Rivers.

1.2

4.1 At 12 o'clock, good view of Saddle Mountain. This is an erosional remnant of submarine basaltic breccia. It is equivalent in age to basaltic flows of the Columbia River Group. A large dike extends from the bottom to the top of the mountain.

1.1

5.2 Lewis and Clark River. Junction, logging road just beyond bridge, keep straight to Saddle Mountain State Park. On right, road cuts along logging road are in mudstone of the Astoria Formation.

1.1

6.3 Gate. Entrance to Saddle Mountain State Park.

0.6

6.9 Parking area, Saddle Mountain State Park and a good view of Saddle Mountain, with several resistant basaltic feeder dikes cutting across the southern face. Baldwin (1952) suggested that Saddle Mountain is an erosional remnant of submarine basaltic pillow lavas and breccias, more than 2,000 feet thick, which were once continuous over much of Clatsop County (extreme northwestern Oregon). Streams cutting through the breccias have removed all but this and a few other remnants which stand as peaks today.

A trail leads from the parking area to the top of Saddle Mountain (4 miles); the hike is a favorite of many. The elevation of the summit is approximately 3,150 feet. The relief is 1,350 feet. An unusual "alpine" flora is found near the summit.

6.9

13.8 Junction, U.S. 26. Turn left to Portland.

END OF ROAD LOG.

FIELD TRIP NO. 4

THE COLUMBIA RIVER GORGE:

BASALT STRATIGRAPHY, ANCIENT LAVA DAMS AND LANDSLIDE DAMS

by

Aaron C. Waters

University of California

at Santa Cruz

March 1973

Figure 1. Looking east up the Columbia River Gorge from above Crown Point. On the left, the fan of Troutdale gravels (T), surmounted by Zion shield volcano, has been incised by Columbia River. Outliers of Yakima Basalt (Y) rest on Ohanapecosh and Eagle Creek Formations which are obscured by landslides. Beacon Rock (B), a plug of olivine basalt, rises in the distance.
South of the river, Crown Point (C) is a remnant of an intracanyon flow, over 650 feet thick, stuck to the south wall. Farther upstream are superposed flows to Yakima Basalt (Y) capped by the north flank (L) of the Larch Mountain shield volcano. (Photo by Oregon State Highway Division.)

THE COLUMBIA RIVER GORGE:

BASALT STRATIGRAPHY, ANCIENT LAVA DAMS, AND LANDSLIDE DAMS

INTRODUCTION

East of Portland, Oregon, the Columbia River is entrenched in a gorge, 65 miles long, across the axis of the Cascade Range. It is not the deepest canyon on the North American continent, but in its primitive state it was among the more spectacular and beautiful (Figure 1). Three of the major Cascade volcanic cones, Mount Hood on the south and Mount St. Helens and Mount Adams to the north, tower above the uplands on either side of the canyon. Lesser Quaternary volcanic cones by the dozen are scattered on the canyon walls, on its floor, and across the entire width of the Cascade Range both north and south of the Columbia. Many of them have repeatedly spilled lava flows down tributary canyons into the main river. Neither they, nor the growing anticlines and faults in the basement rocks beneath the Quaternary and Pliocene volcanic cones, were able to bar the river from its path across the Cascades. Instead the Columbia sawed them into natural geologic sections, well displayed on the canyon walls.

Until temporarily trapped in giant millponds by man-made dams, the Columbia River raced through its deep canyon in a series of boiling rapids, whirlpools, and low waterfalls. It was a wild river that defied the early immigrants, forcing most of them to detour around the south side of Mount Hood so as to avoid the great ledges and cliffs of basalt that barred passage by horse and wagon along the Columbia's banks. A few pioneers risked and conquered the river's rapids by building substantial log rafts and floating downstream. Today, in only one hour's time, you can whizz through the gorge via tunnels and over bridges on a 4-lane divided freeway. The smell of paper pulp and the acrid smoke from aluminium plants prevade the air. Burning waste from sawmills replaces the fires of the Indian villages. No longer do the salmon leap the falls at Celilo or streak through the rapids at Cascade Locks. Ugly slashes through the forest mark the routes of transmission lines which carry electric power from the turbines at Bonneville and The Dalles. The huge "burns" from uncontrolled fire following early logging operations are now healing beneath a scab of red alder, huckleberry, and second-growth conifers. The tributary creeks and small rivers, most of them still crystal clear and uncontaminated, continue to spill into the Columbia over the spectacular waterfalls or through the lovely "dells" and "gorges" (box canyons) that have delighted all travelers fortunate enough to take the time to see them.

My geologic mapping in the Columbia River Gorge started in 1955, and was supported by the U. S. Geological Survey as a contribution to the geologic map of Oregon (Wells and Peck, 1961). After publication of this map, additional field work, particularly on the Washington side of the river, was resumed but many times interrupted and recessed. The mapping is now essentially complete and should be published in a few years.

THE FIELD TRIP

The geology of the Columbia River Gorge is complex in detail but orderly in its major features. This guidebook presents only a few selected areas of special interest, chosen chiefly because of their easy accessibility by highway. An abbreviated column showing the stratigraphic section is given (Table 1), but most details of the stratigraphic and petrologic history are condensed or omitted. Instead, attention in this guidebook will be focused primarily on three relatively simple problems: 1) determining the flow-by-flow stratigraphy in two areas of the Yakima Basalt (one formation of the Columbia River Group of flood basalts). 2) description of two lava dams of high-alumina olivine basalt which temporarily blocked the Columbia River after it had cut to approximately its present level. 3) the origin and nature of the landslides and debris flows (several are still moving) which continually crowd the Columbia River as it works down the dip slope of a major unconformity.

Stops are scheduled to see at least one representative outcrop of each of the major stratigraphic units. Weather permitting, stops from view points are also scheduled to "armwave" at some of the major structural, geomorphic, and igneous features.

The most useful topographic maps of the Columbia River Gorge are six 15' quadrangle sheets published by the U.S. Geological Survey. From west to east they are Camas, Bridal Veil, Bonneville Dam, Hood River, White Salmon, and The Dalles. The Forest Service has made available an excellent map and brochure showing roads, trails, campsites, and recreational areas. Published geologic maps are few, cover only small areas, and are mostly out of date. Early reconnaissance descriptions are by LeConte (1874), I. Williams (1916), and Bretz (1917).

THE STRATIGRAPHIC SECTION

The following descriptions of the formations, arranged in order of decreasing age, supplement the information listed in the stratigraphic column of Table 1.

Ohanapecosh Formation equivalent

The oldest rocks exposed in the Columbia River Gorge are zeolitized and argillized lavas and volcaniclastic rocks.

Stop 1-4 * provides a typical example. On the north side of the Columbia they underlie extensive areas between Rock Creek and Little White Salmon River. South of the Columbia they are masked by overlying formations except in a few small patches near the river bank.

These altered volcanic rocks are considered to be the equivalent of the upper Eocene Ohanapecosh Formation (Fiske, Hopson, and Waters, 1963) of Mount Rainier National Park; the evidence, somewhat inconclusive, is as follows:

1. When traced westward into the Bonneville Dam and adjacent quadrangles, increasing amounts of olivine basalt, thought to be the eastward extension of the Eocene Goble basalts, interfinger with the dominantly andesitic lavas and volcaniclastic rocks typical of the normal Ohanapecosh equivalent.

2. Reconnaissance tracing of the Ohanapecosh Formation southward from Mount Rainier National Park disclosed widespread development of rocks with similar lithology and zeolitic alteration in all of the deep canyons between Mount Rainier and the Columbia Gorge.

The base of the Ohanapecosh equivalent has not been found in the Columbia Gorge area. A section of dominantly volcaniclastic rocks exposed along logging roads in Bear Creek canyon, north of Carson, is more than 5,000 feet thick without duplication. Between Carson and Rock Creek altered andesitic and basaltic lavas, interbedded with zeolitized volcaniclastic rocks, are equally thick, so it is likely that the total thickness of the Ohanapecosh equivalent exceeds 10,000 feet.

The most striking feature of these rocks is their uniform and widespread zeolitic and argillic alteration. As a result of this alteration, all primary joints, vesicles, and other cavities were sealed, making the formation almost totally impermeable to ground water. Matrix and clasts of most volcaniclastic rocks are so tightly intergrown and cemented with heulandite, celadonite, quartz, chabazite, chlorite, clay minerals, and other secondary products that when struck with a hammer the rock breaks across the lava fragments instead of following the matrix around them. Lavas generally appear to be less altered than pumiceous pyroclastic rocks, but in many the glassy matrix has completely crystallized, feldspar phenocrysts and microlites are changed to mixtures of laumontite and celadonite, and joints in the lava are sealed with a variety of zeolites, quartz, and epidote.

* Stops are numbered according to day: 1-4 is the 4th stop on the first day, 2-1 the 1st stop on the second day.

Table 1. Stratigraphy, Columbia River Gorge

	A. Alluvium, talus, active landslides, and debris flows.	
PLEISTOCENE-HOLOCENE	B. Olivine basalt lavas, cinder cones, and hyaloclastic deposits; examples: Big Lava Bed, cinder and lava cones of Hood River valley, lavas and delta from Wind River valley, Mt. Defiance and Starvation andesites, major strato-volcanoes - Mounts St. Helens, Hood, and Adams.	
PLIO-PLEISTOCENE	Widespread olivine basalt volcanism. Examples: Larch Mountain, Mt. Zion, Underwood and White Salmon shield volcanoes, Boring lava of Willamette valley.	
	Troutdale gravels:	Depositional fan from Columbia River.
	Dalles Formation:	Chiefly stream deposited volcaniclastic rocks; local airfall and nuée deposits.
PLIOCENE		
	Ellensburg Formation:	Stream deposited pumice-rich volcaniclastic rocks; local mudflow and airfall deposits.
MIOCENE	Yakima Basalt:	Flood basalts; thick tholeiitic flows, pillow basalts, and hyaloclastic tuffs.
LOWER MIOCENE ?	Eagle Creek Formation:	Coarse cobble gravels and other volcaniclastic rocks; mostly andesitic.
UPPER EOCENE	Ohanapecosh Formation equivalent:	Zeolitized and argillized lavas and volcaniclastic rocks, chiefly of andesitic composition, but increasing in basalt toward the west.

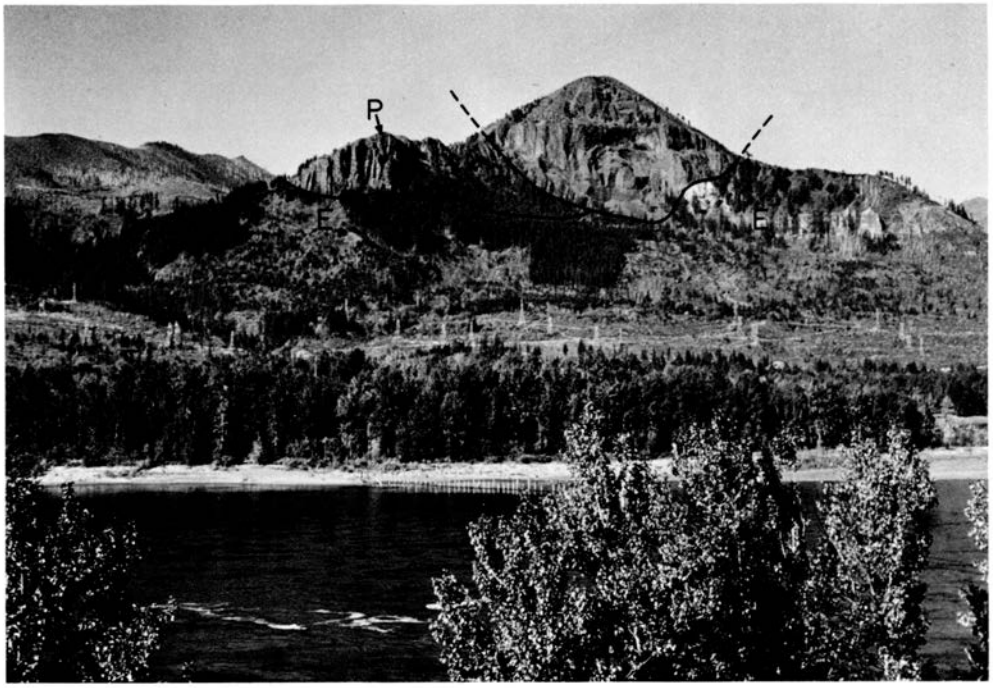


Figure 2. South face of Hamilton Mountain. The basal flow of Yakima Basalt (Y) fills an old canyon in the Eagle Creek Formation (E). (P) is an earlier fill of stratified palagonite tuff.

Figure 3. Pomona Basalt flow, Mosier syncline, showing typical wedge-shaped joints.

At Mount Rainier National Park thick tuff-breccias capped by a succession of thin graded tuffaceous beds are typical of certain parts of the Ohanapecosh Formation. These were interpreted as products of pyroclastic eruptions under water, distributed outward from the vents by turbidity flows (Fiske, 1963). The same mechanism seems appropriate for similar tuff-breccias and thin graded-bedded tuffs in the Ohanapecosh equivalent of the Columbia River Gorge, but a larger proportion of the pyroclastic rocks in the Gorge appear to be blocky subaerial nuee ardente, mudflow, and slurry flood deposits, such as those described and photographed by James G. Moore during the recent eruptions of Mayon Volcano. Some Ohanapecosh tuff-breccias in the Columbia Gorge area clearly overwhelmed forests, as shown by abundant charred wood, and (more rarely) rooted stumps engulfed at their base.

The pervasive zeolitization of the Ohanapecosh equivalent took place before the overlying rocks of the Eagle Creek Formation were deposited. Immediately beneath the unconformity, the zeolitized Ohanapecosh rocks also have been deeply weathered and converted to a purplish-brown to red-brown clay saprolite, which is in many places 10 to 100 feet thick. Reworked bits of this clay stain some of the basal beds of the Eagle Creek, normally buff to pale gray, to various shades of pink or reddish brown. As noted later, this slippery clay-rich saprolite has been of major importance in the development of the extensive debris-flows and landslides on the north wall of the Columbia River Gorge.

Eagle Creek Formation

The Eagle Creek Formation was named by Chaney (1918), and he continued to discuss its fossil flora, mostly obtained from beds near the mouth of Eagle Creek, in later publications (1920, 1959). His latest estimate of its age is lower Miocene. At the type area on Eagle Creek, an Oregon tributary of the Columbia, the formation is chiefly volcaniclastic silts, sandstones, and conglomerates. The greatest thickness exposed south of the Columbia is 250 feet on McCord Creek. North of the Columbia, however, far thicker and more complete sections are exposed in the crescentic scarp at the head of the Bonneville landslide and also on the upper slopes of nearby Rock Creek canyon. Beneath the Yakima Basalt which caps Greenleaf Peak (Figure 9) are a little more than 1,000 feet of bedded volcanic conglomerate and tuffaceous sandstone.

Clasts in the Eagle Creek conglomerate consist almost entirely of hornblende-pyroxene andesite. The tuffaceous and sandy sediments formerly contained much pumice and glass shards, now altered to clay minerals. Cementation of these rocks is chiefly by clay and carbonate. Silicified wood is abundant at many levels within the formation.

The Eagle Creek Formation is an accumulation of volcaniclastic rocks derived from local centers. Most of it was deposited from mudflows and slurry floods washed from nearby active volcanoes. Sills and plugs of similar composition cut Ohanapecosh rocks north and east of Rock Creek, and other small intrusives, now surrounded by alluvium on the south bank of the Columbia east of Cascade Locks may have been feeders of the Eagle Creek deposits. One basaltic lava flow was noted in the Eagle Creek Formation north of Columbia River. Much later (Pliocene to Holocene), plugs and dikes of olivine basalt cut the Eagle Creek Formation at Red Bluffs and at other localities. The formation thins rapidly when traced east and south from Greenleaf Peaks, but its extension to the north and northwest has been removed by erosion. There is no reason to suppose that it extended far from present outcrops, however. Representative examples of Eagle Creek rocks will be seen at Stop 1-2.

As previously noted, the base of the Eagle Creek Formation rests on a saprolite which marks an ancient zone of deep weathering developed upon tilted and eroded Ohanapecosh rocks. The top of the Eagle Creek is also an erosional unconformity. The formation had been dissected to a rugged landscape with a relief of several hundred feet at the time the basal flows of Yakima Basalt encroached upon this area from the east. The south face of Hamilton Mountain (Figure 2) shows an excellent cross section of a deep valley cut into the Eagle Creek rocks and then filled by a thick flow of Yakima Basalt.

Yakima Basalt

The Yakima Basalt is one of the most widespread formations of the Columbia River Group (Waters, 1961). In the eastern part of the area covered by this field trip, the Pomona Flow, (Figure 3) and several of the units named by Mackin (1961), are easily recognized (Figure 4). These uppermost flows of Yakima Basalt are olivine bearing and are chemically dissimilar (see Snavely and MacLeod, in press) to the "normal"

Yakima Basalt which underlies them in central and eastern Washington. The latter is a silica-rich tholeiite verging on andesite. The normal Yakima flows are well exposed in the cores of the Bingen and Ortley anticlines (Figure 12). At many other places their thick flows can be viewed as continuous layers on the canyon walls, and are easily traced for several miles (Stops 2-2 to 2-6).

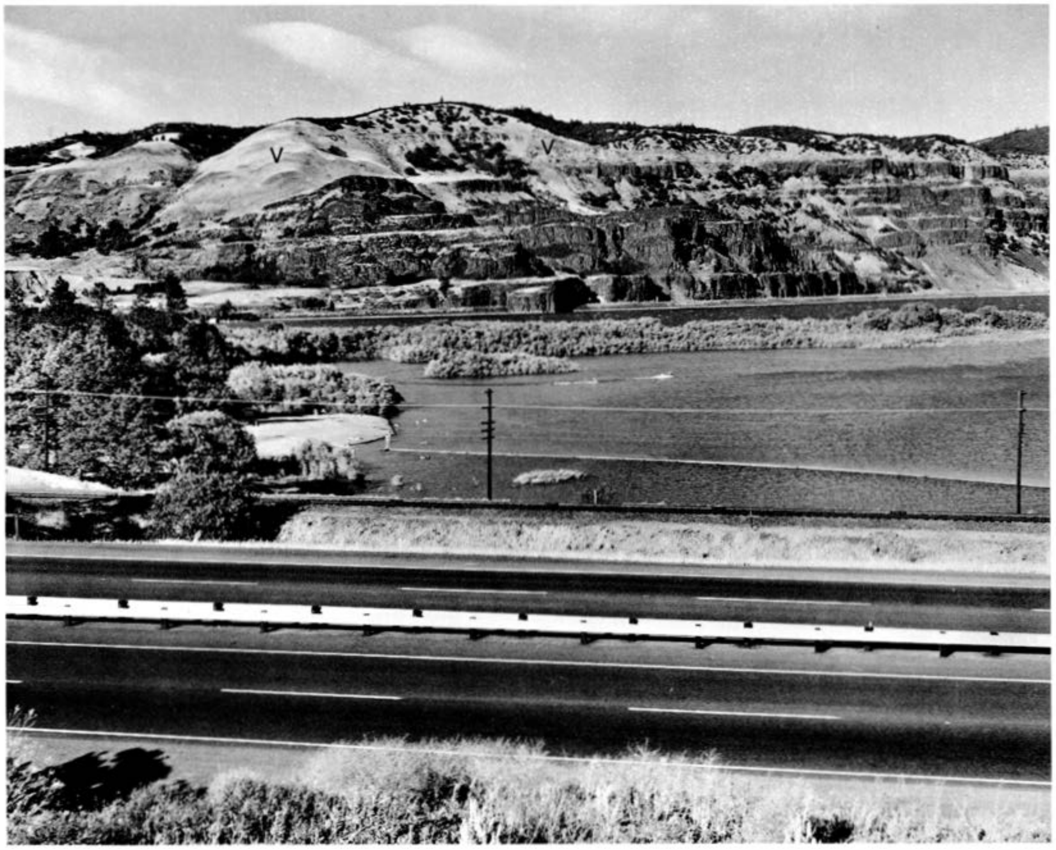


Figure 4. Yakima Basalt and Ellensburg Formation east of Lyle. Volcaniclastic rocks (V) overlie the Pomona Flow (P), which rests on four to five flows of the Priest Rapids member. (Photo by Oregon State Highway Division.)

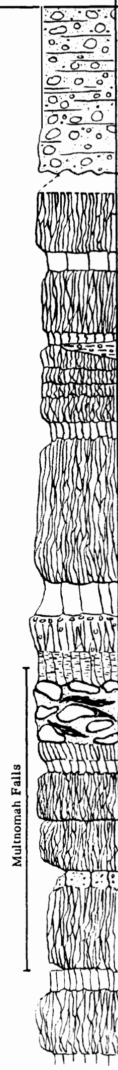
In recent years there has been much interest in developing a flow-by-flow stratigraphy for these basalts and in finding criteria useful in correlating individual flows whose surface outcrops are interrupted by erosion or by a cover of later deposits. These problems will be discussed at Stops 1-12 and 1-13.

In the western part of the Columbia Gorge, the Yakima Basalt has not been as thoroughly studied as in the area east of the Cascades. Tentatively, it appears that these rocks represent deeper levels in the Yakima Basalt than those seen at Yakima or in the eastern Columbia Gorge areas. An excellent section of this western part of the formation is well exposed on Multnomah Creek, and characteristic features of the flows are summarized in Figure 5. A part of this section will be seen behind the Multnomah Falls at Stop 2-4, and additional opportunity to examine the basal flows will be provided at Stops 2-3, 2-5, 2-6, and 2-7.

An interesting feature is the great bluff of basalt at Crown Point (Figure 1 and Figure 6, and Stops 1-1 and 2-7). This is a remnant of a flow of Late Yakima Basalt that filled a canyon more than 680 feet deep. This canyon was eroded into basalts which are the continuation of those exposed at the Multnomah Creek section. Is this canyon the first record of an ancestral Columbia River through the Columbia Gorge?

Stratigraphic Section of the Yakima Basalt

Along Multnomah Creek, Multnomah County, Oregon



FM	MBR	Thick	Lithology	Description
Troutdale	12.	Variable > 200'		Troutdale gravels. Cobbles are chiefly Yakima basalt, but a wide variety of other rock types. Sandy to tuffaceous matrix. Unconformity
Yakima Basalt	11.	120'		10' covered interval. Hackly entablature, collonade of 4' diameter columns. Intersertal texture, with abundant tachylyte pools. Abundant microphenocrysts of both plagioclase and pyroxene.
	10.	85'		Entablature; blade-like to wedge-like jointing; collonade 1' wavy columns. Intersertal, tachylyte rich flow, nonporphyritic.
	9.	65'		Interbed of tuffaceous silty clay, 1 to 2 feet thick. Three-tier flow, no collonade. Glassy texture, with small vesicles; intersertal and nonporphyritic.
	8.	50'		Similar to flow above, but entablature and collonade present. Intersertal, numerous microphenocrysts of plagioclase and pyroxene.
	7.	225'		Entablature: very long, small to bladed columns 3" to 6" thick. Collonade: short, massive columns 5' to 8' diameter. Intersertal, and rich in tachylyte in the entablature; collonade more crystalline but fine-grained and rich in brown crystallite filled glass. Both have sparse microphenocrysts of plagioclase.
	6.	80'		10' vesicular top and scattered vesicles throughout entablature. Collonade has platy joints. Abundant microphenocrysts of plagioclase and pyroxene, and rare phenocrysts 1 cm long. Intersertal texture.
	5.	75'		Pillow lava. Many elongated streaks of lava and of hyaloclastic debris between patches of pillows. Abundant microphenocrysts of plagioclase and pyroxene.
	4.	35'		Thin glassy flow with well formed collonade and entablature.
	3.	120'		Two tiers of hackly jointed material. No collonade. Intersertal, scattered microphenocrysts of plagioclase and a few of pyroxene.
	2.	140'		Blocky, vesicular zone at top which forms the marked horizontal crevasse 100' above the base at Multnomah Falls. Entablature: Hackly thin columns; collonade: 2 to 4 foot columns. Intersertal, sparse microphenocrysts of plagioclase and pyroxene. Abundant interstitial chlorophaeite.
	1.	70'		Hackly entablature, weathering into rounded forms; thin collonade. Intersertal, abundant microphenocrysts of plagioclase and pyroxene.
		50'		Covered interval to level of Columbia River.

Figure 5. Stratigraphic section of the Yakima Basalt on Multnomah Creek.

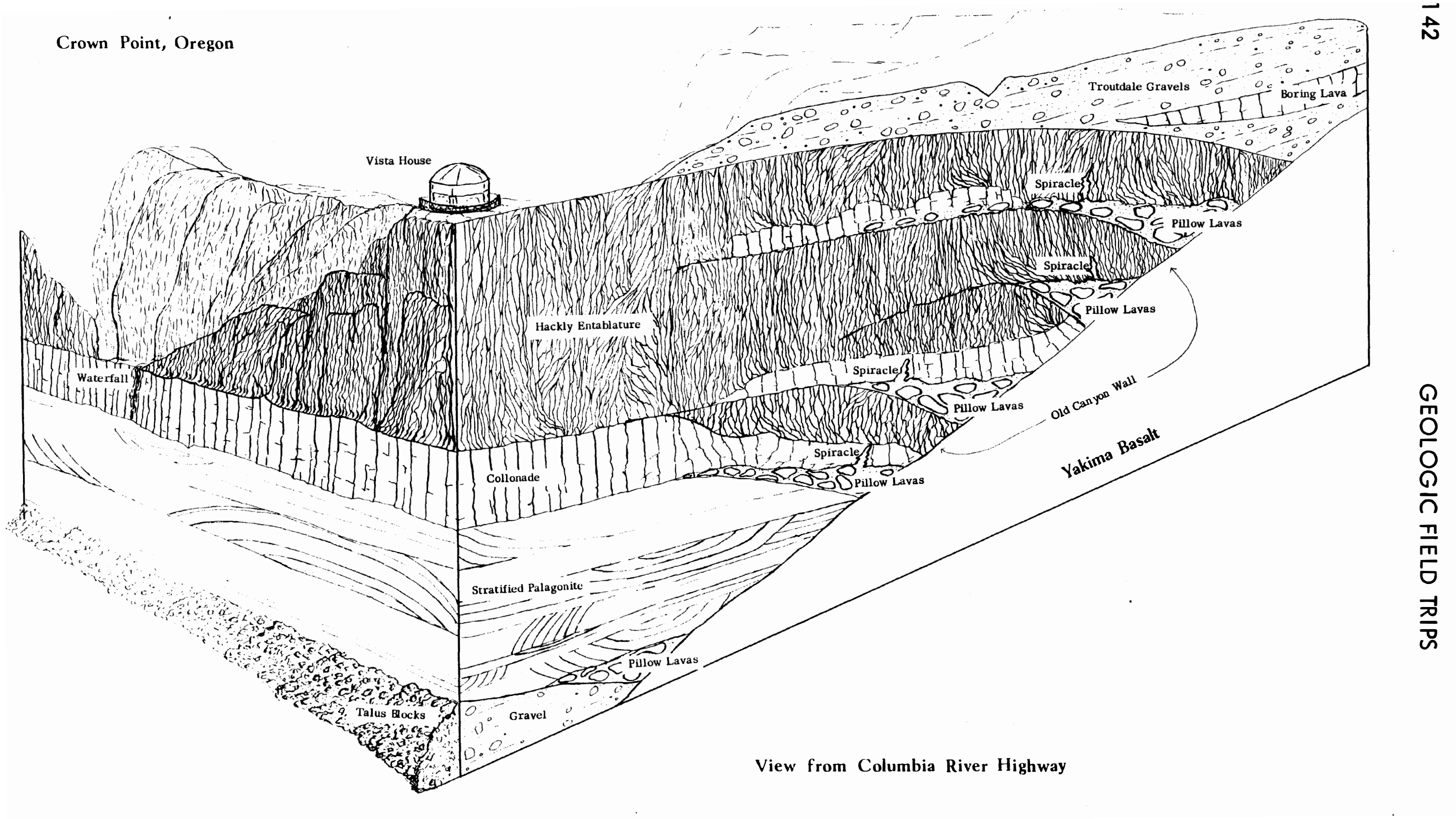


Figure 6. Block diagram of the remnant of an intracanyon lava fill at Crown Point.

The basalts in the western part of the gorge have a uniform south-to southeast-dip of a few degrees. As a result, erosion removed the basalt from wide areas on the Washington side of the river, exposing the Ohanapecosh and Eagle Creek Formations beneath. On the Oregon side, the Columbia River continuously undermines the basalt along this unconformity; therefore, great bluffs of Yakima Basalt rise steeply above the narrow accumulations of talus, landslide, and stream deposits that line the south bank of the Columbia. Three thick flows with short collonades and remarkably thick and resistant entablatures are exposed at Cape Horn on the Washington side of the River, and on the Oregon side these three resistant flows are responsible for the exceptional series of high waterfalls in the Oregon tributaries that enter Columbia River between Dodson and Crown Point (Stops 2-2, 2-4 and 2-6).

The upper surface of the Yakima Basalt also is an unconformity. In the western end of the gorge, the basalt is generally overlain by the Troutdale gravels (Figure 1). In the central part, where the Columbia crosses the higher parts of the Cascades, Pliocene to Holocene olivine basalts, olivine andesites, and pyroxene andesites (together with their characteristic mudflows and blocky nuée ardente deposits) cap the deeply eroded basalts (Figure 7 and Figure 1). In the eastern part of the gorge volcaniclastic rocks, including the Dalles Formation and Ellensburg Formation, lie directly upon the youngest flows of Yakima Basalt (Figure 4 and Figure 12). Farther northeast, in the Yakima district, this Late Yakima Basalt is interbedded with the Ellensburg Formation.

Ellensburg, Dalles, and Troutdale Formations

Above the Yakima Basalt, in various structural and physiographic settings, are conglomerate and volcaniclastic rocks which contain vanishingly small to large amounts of white to pale-buff, fine-grained quartzite clasts, some of which weather with a reddish rind.

Such quartzite gravels have been a cause of considerable confusion to workers in the Columbia Gorge. One would expect that anything with such esoteric-looking pebbles could be correlated from place to place, but these pebbles are jokers in such plans. All that they mean is that the deposit containing them received contributions from streams that drained areas of Precambrian quartzite in northeastern Washington, British Columbia, or Idaho. They are therefore characteristic of all deposits along the Columbia River from Pliocene to the present. By no means does their presence in two different rocks indicate equivalence in age. The "Satsop Gravels" of Bretz (1917) are not necessarily Pleistocene, nor are the quartzite-bearing gravels at Underwood (Stop 1-11) correlative with the coarse gravels interstratified in the Yakima Basalt directly across the Columbia at the mouth of Hood River, although both were included as "typical areas" of their "Hood River Formation" by Buwalda and Moore (1930).

The older literature offers no ready solution to the confusing relationships between these fluvial deposits. My tentative solution, which probably will be later modified, refined, or abandoned, is to accept as valid mapping units three widespread, named, Pliocene formations - the Ellensburg Formation, Dalles Formation, and Troutdale Formation listed in order of decreasing age. In the eastern part of the gorge the Ellensburg and Dalles Formations are relatively easily distinguished in the Mosier and Dalles synclines by superposition (at a few places), by differences in the direction of sediment transport, and by differences in degree of deformation. Yet these differences become ambiguous when we attempt to apply them to outcrops only 10 miles or more on either the north or south side of the Columbia Gorge. For example, paleocurrents that deposited the Ellensburg Formation, now recorded in outcrops on the west flank of the Ortley anticline, were traveling west, whereas those which piled up the Dalles Formation at its type locality were moving east and north. Yet the Ellensburg Formation in central Washington shows paleocurrent evidence of having been derived chiefly from freshly erupted pyroclastic debris out of stocks and small batholiths located along the crest of the Cascades to the west. A similar source in the Oregon Cascades is inferred for the dominant andesitic to dacite lava cobbles and pyroclastic debris in the Dalles Formation of north central Oregon.

The Troutdale Formation presents less difficult problems. All geologists who have studied it agree that it is a huge gravel fan deposited by ancestral Columbia River as it debouched into the Willamette basin while struggling to maintain its course across the growing anticlines and through the actively erupting late Pliocene-Pleistocene volcanic fields. The 750-foot section of Troutdale gravels exposed on the north bank of the Columbia southwest of Mt. Zion volcano (Figure 1) has large cobbles which are over 95 percent Yakima Basalt, and its matrix is mostly basaltic glass or palagonitic debris (a good deal of which,

Figure 7. Looking east up the Columbia River Gorge from a point above Shellrock Mountain. The active Wind Mountain debris flow (DF) has squeezed Columbia River to the south bank. Shellrock Mountain stock (S) and a part of the Wind Mountain stock (W) are in the foreground. Part of Mount Hood volcano at extreme right, Mount Defiance volcano (MD) in middle distance, Hood River Fault Scarp on skyline. Yakima Basalt (Y) lines most of canyon. (Photo copyright by Delano Photographics, Portland.)

however, is from the high-alumina olivine basalt of the High Cascades). Yet in every outcrop a few quartzite and quartz pebbles will be found, along with resistant pebbles from the siliceous granophyric dike rocks that abound in areas on the roof and edges of the Chelan batholith in central Washington. We will see an outcrop of typical Troutdale gravels at Stop 2-10.

When traced eastward into the higher parts of the Cascades the distinction between the Troutdale gravels and the Dalles Formation is less easy. The Troutdale acquires more hyaloclastic and pyroclastic debris, and the percentage of coarse Yakima Basalt pebbles diminishes. An early stage of this change is seen in the roadcuts at Stop 2-8 just west of Crown Point. Farther east, a thick section of Troutdale gravels appears in the headwaters of Bridal Veil and Multnomah Creeks beneath high-alumina olivine basalts from Larch Mountain. By the time one gets to the headwaters of Eagle Creek, or to the stratified palagonites (with rare pebbles of quartzite) that merge through pillow lavas with the olivine basalt cap of the Benson Plateau, the distinction between Troutdale and Dalles is lost. Although in places unconformities lie between them, I suspect that the deposition that produced these three formations is a continuum in time. The striking local differences that we see between them are merely the changing effects produced in different depositional basins by episodic to continuous orogeny and volcanism.

Deposition of quartzite-bearing gravels did not stop with the completion of the Troutdale gravel fan. Stream terraces of Columbia River, the deposits upstream from various lava dams (for example at Stop 1-6), the deposits left by the Spokane Floods, the channel gravels of present Columbia River, and gravels dredged from the submarine canyon of Columbia River on the Blake Plateau (Griggs, and others, 1961) all contain the ubiquitous quartzite, and also the granophyre pebbles associated with the Chelan batholith.

Pliocene to Holocene basalts and andesites

The High Cascades of northern Oregon and southern Washington are a complex volcanic field of overlapping shield volcanoes composed mostly of high-alumina olivine basalt and olivine andesite. Rising above the general level of this shield-volcano upland are the giant stratovolcanoes, of which Mount Adams, Mount St. Helens, and Mount Hood are the nearest ones to the Columbia River Gorge. These are mostly pyroxene andesite and olivine andesite, with a little pumiceous pyroxene dacite.

Eruptions of olivine basalt began during the later stages of deposition of the Dalles Formation of central Oregon and continued during and after the building of the Troutdale fan. Perhaps the youngest representative in the Columbia River Gorge is the Big Lava Bed. It covers a large area north of Columbia River in the Willard quadrangle (Figure 8). Flows forming the upper part of the Big Lava Bed traveled 18 miles from the crater and entered Columbia River at Drano Lake (Stop 1-10). The Big Lava Bed is so young that vegetation has not yet gained a foothold over much of its course.

ANCIENT LAVA DAMS

An older series of intracanyon flows (greater than 35 thousand years by radiocarbon dating) erupted from Trout Creek Hill, found their way into the Wind River canyon, followed it to its mouth, and entered Columbia River on a front over 1 mile wide (Figure 8). Possibly reinforced by intracanyon flows out of Herman Creek or from other local vents, the Wind River flows blocked Columbia River with a lava and hyaloclastic dam that persisted long enough for Wind River to build a delta at least 150 feet thick and one mile long into the lake above the dam before the Columbia River destroyed it (Figure 8, and Stops 1-6, 1-7). Whether the remnants of the lava dam on the Oregon shore at Herman Creek and in scattered outcrops downstream were erupted from vents on the Oregon side, or are parts of the Wind River flows that extended to the Oregon shore, is not certain. The deposit damming the mouth of Herman Creek has a top at least 100 feet higher than the surface of the lava at the mouth of Wind River, but this could be the result of warping or of heaving beneath a special kind of landslide which is prevalent along the base of the high Yakima Basalt cliffs south of Columbia River.

Near the town of Hood River another former lava dam, built partly of hyaloclastic debris and pillow lavas, received contributions from a whole series of different olivine basalt volcanoes located on both the north and the south sides of the Columbia. Its inferred position and sources are shown in Figure 8. We

Lava and Landslide Dams in the Columbia River Gorge

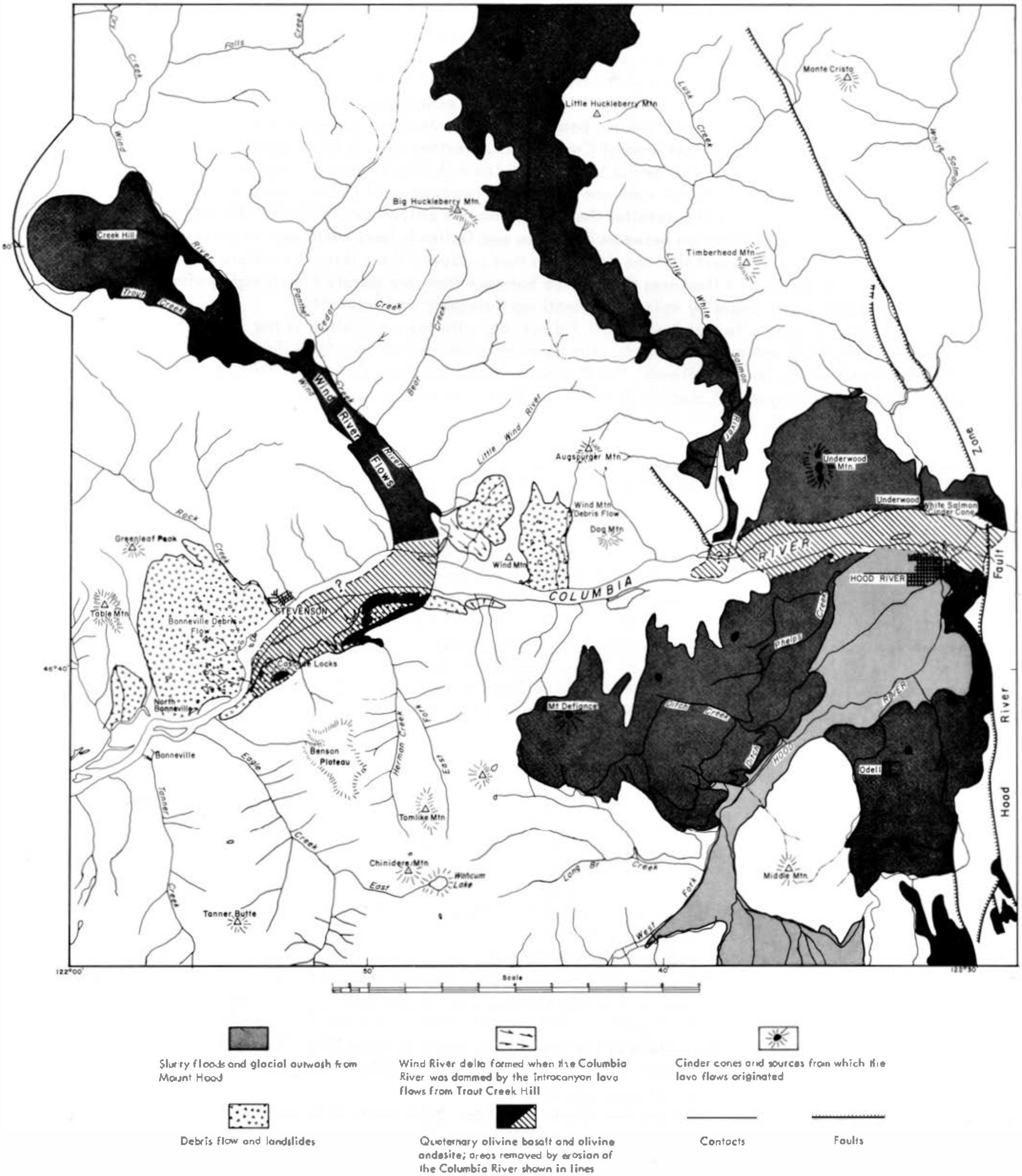


Figure 8. Map of former lava dams, and of active landslides in the western part of the Columbia River Gorge.

will have opportunity to visit, or view from a distance, this dam at Stops 1-10, 1-11, from our overnight stop at Hood River Inn, and at Stop 2-1. At Mt. Defiance (Figure 7) and Starvation Butte, south of the Columbia River, lava cones of andesite have since grown above the vents that produced a part of this olivine basalt fill.

The petrology of the olivine basalt and olivine andesite shield volcanoes, and of Mount Hood, Mount St. Helens, and Mount Adams is being actively investigated by several geologists and will not be treated on this trip.

LANDSLIDES AND DEBRIS FLOWS OF THE COLUMBIA RIVER GORGE

The Columbia River Gorge is a classic area for the investigation of rock falls, landslides, and especially debris flows. It also has interesting examples of hydraulic vertical rise along some stretches of the river bank on the Oregon side. These are somewhat similar to the Gatun slides of Panama Canal. My work on Columbia River Gorge slides is not detailed - to me they have been a nuisance that hides the bedrock geology - but certain general ideas as to the origin and particular kind of behavior shown by different slides is definitely related to the regional geology, and it is these aspects that will be treated on the field trip.

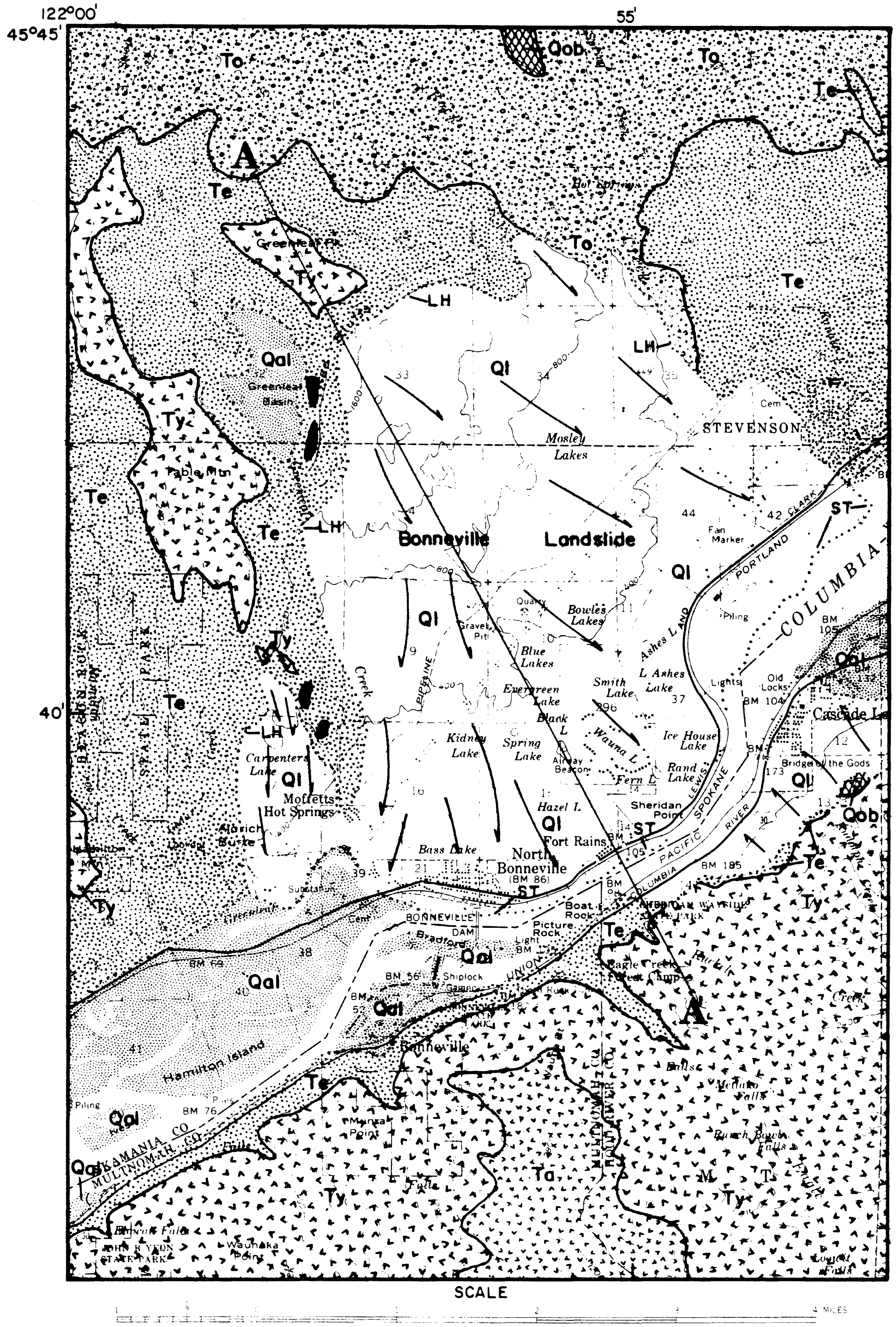
The Bonneville landslide and debris flow

The north side of Columbia River from Cape Horn to 2 miles east of Wind Mountain is bordered almost continuously by extensive debris flows that head in scarps whose bases are loaded with talus, rock falls, and landslide debris. Of these the largest and most typical is the Bonneville debris flow (Figure 9). Another debris flow that is particularly interesting because its actively moving front is causing much distortion of tributary roads, highway, and railroad, and which forced the abandonment of a transmission line (now relocated around the slide's upper end), is east and northeast of Wind Mountain. Other landslides and debris flows of the same kind, but of smaller volume, fill the lowlands between Cape Horn and Prindle, between Prindle and Archer Mountain, and between Archer Mountain and Beacon Rock.

The culprit in every case is the thick clay saprolite developed on the Ohanapecosh zeolitized rocks before they were covered unconformably by the Eagle Creek Formation or the basal flows of Yakima basalt. The unconformity at the top of the Ohanapecosh, with its saprolite cap, slopes gently (2° to 10°) toward Columbia River. Rainwater, penetrating the permeable Yakima Basalt along numerous columnar and hackly joints, is transmitted deeper by wider-spaced vertical joints in the Eagle Creek conglomerates and sandstones. Water cannot enter the Ohanapecosh Formation at most places because all joints and other openings have been sealed by the zeolitization, celadonitization, and argillization which affected these rocks. So water piles up at the saprolite boundary and converts the saprolite to slippery clay. Then the vertically jointed formations above begin to fall, tilt, and glide downslope on this unstable and well-greased skid-board. (See Figure 9, especially the cross-section, which shows how the landslide is encroaching on the remaining undisturbed remnants of Yakima Basalt and Eagle Creek Formation).

This simple mechanism accounts for all major landslides and debris flows along the north side of the river. The toe of the flows glides into the Columbia River, which, prior to the building of the man-made dams, was powerful enough to carry the debris away. However, the forward motion of the active western part of the Bonneville slide did force the river to the southern bank, causing a big rounded bulge in the otherwise straight course of the river and producing the rapids at Cascade Locks (Figure 9). Similarly, the lobe of the active Wind Mountain slide has reduced the normal width of the river by half.

In Pleistocene to Holocene time, it is possible that some spring, as the frost melted out of the deeper parts of the Bonneville slide, downslope motion was resumed with enough speed to temporarily dam the Columbia River and give rise to the Indian legend of the Bridge of the Gods. The Wind River lava dam, a few miles farther upstream, seems definitely too old to account for this legend.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Evergreen Lake
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Wauna L
Ice House Lake
Carpenters Lake
Ql
Moffetts Hot Springs
Kidney Lake
Spring Lake
Rand Lake
Fern L
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Fort Rains
Bass Lake
North Bonneville
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BONNEVILLE DAM
Bradford
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Figure 9.

Geologic Map of Bonneville Landslide Area

EXPLANATION

Quaternary

Qal — Alluvium and stream terrace deposits

Ql — Landslides

Unconformity

Qob — Olivine basalt flows (Intrusive masses shown in black)

Unconformity

Pliocene

Ta — Pyroxene andesite and olivine andesite flows

Unconformity
(A few patches of Troutdale Formation occur here)

Miocene

Ty — Yakima Basalt (thick flows of tholeiitic basalt)

Unconformity

Te — Eagle Creek Formation (andesitic conglomerate, sands and silts)

Unconformity
(Saprolite at this unconformity indicated in black in cross section)

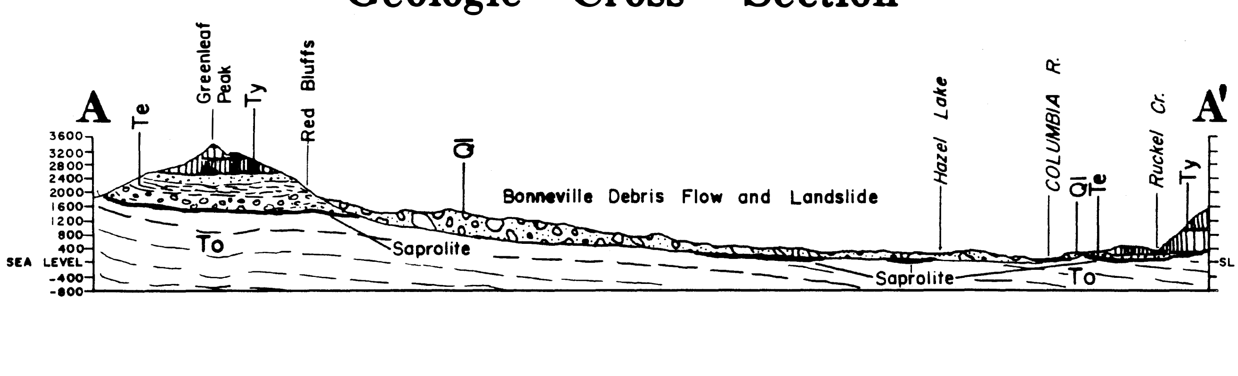
Eocene

To — Ohanapecosh Formation equivalent (Zeolitized and argillized volcaniclastic rocks)

LH — Landslide headscarp

ST — Submerged toe

Geologic Cross Section



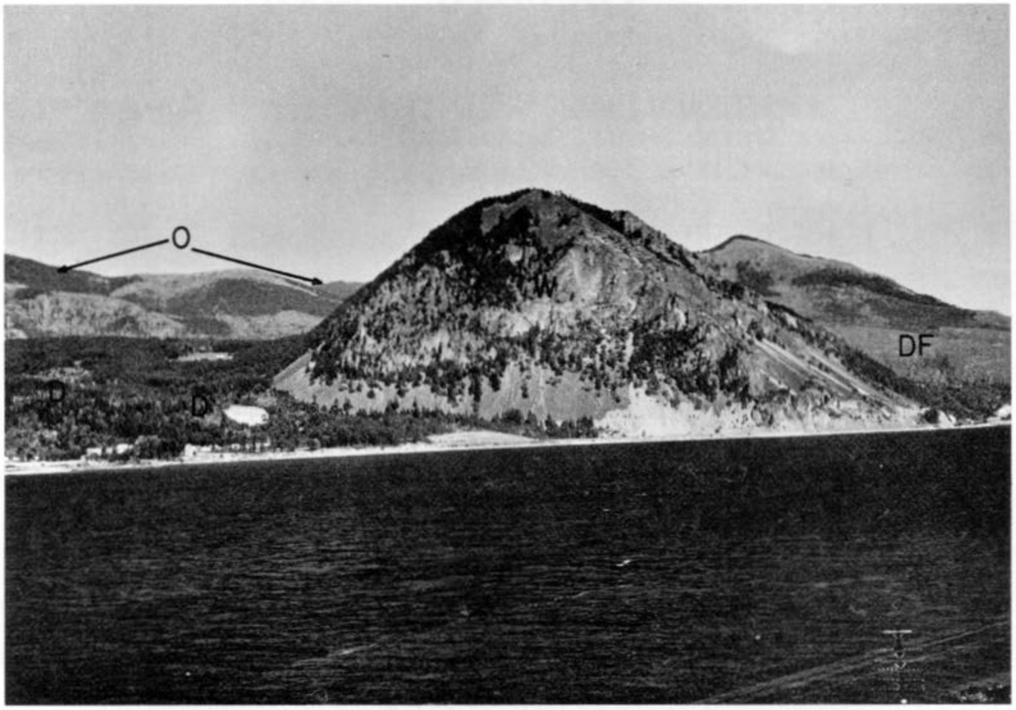


Figure 10. Wind Mountain Stock (W); Ohanapecosh Formation (O); delta of Wind River behind lava dam (D); debris flows and landslide (DF).

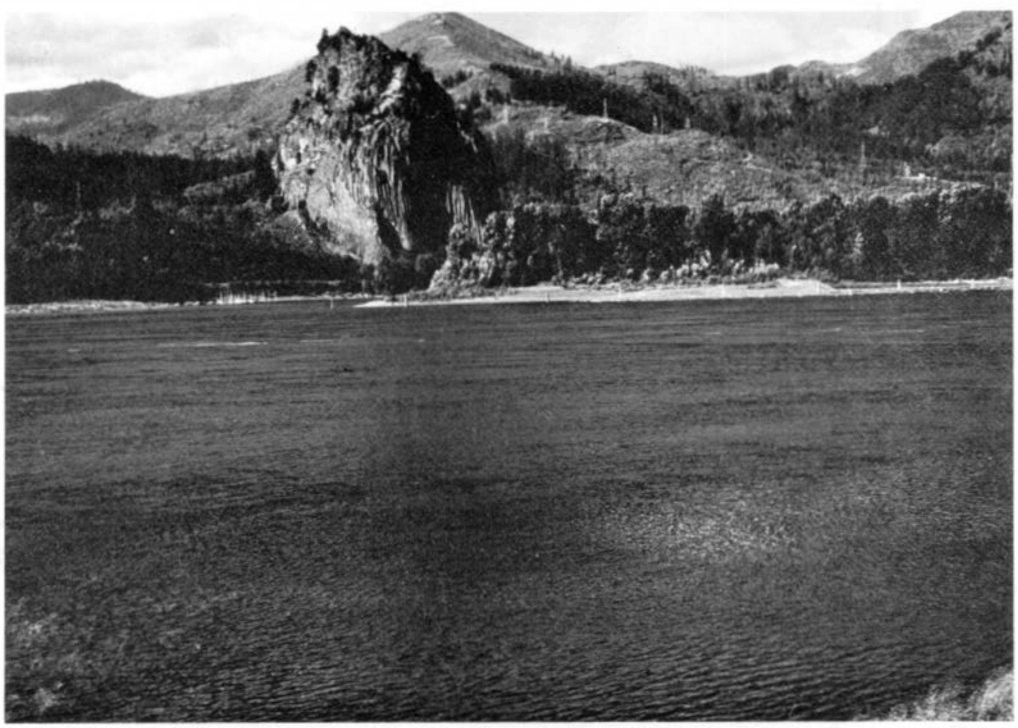


Figure 11. Beacon Rock, an eroded plug of olivine basalt rises from the north bank of Columbia River.

Hydraulic ram landslides on the south side of Columbia River

The outcrop trend of the top of the Ohanapecosh Formation slopes down the west side of Dog Mountain and crosses the Columbia River just east of the base of Shellrock Mountain, where it is bowed up slightly by the Shellrock stock. It then bends west and follows rather closely the base of the line of high basalt cliffs that overlook the river along its south side as far west as Dodson. In this area definite outcrops of the Ohanapecosh Formation are small and few and occur mostly in the area immediately around Cascade Locks. Evidence that the Ohanapecosh Formation is near the surface throughout this area, however, is afforded by fragments of Ohanapecosh saprolite in the talus and landslide debris. East of Wyeth, red mud boils up and spreads over the sands near the highway each spring, and during construction of the roadbed similar deposits from mud boils were encountered in a few areas to the west. The base of the Eagle Creek Formation is exposed in the little amphitheater near the mouth of Dry Creek, and Ohanapecosh saprolitic mud is squeezing out from beneath it.

At some points along the highway between Shellrock Mountain and Dodson, trouble with an unusual kind of slow earth movement is occurring. Over small areas, generally less than 500 feet long, the highway is heaving up in mounded masses. Some seem to be related to swelling of the toes of short landslide tongues, others are more enigmatic in form and movement. Unloading of thousands of cubic yards of loose talus from the slopes above one of them has not alleviated the problem. The saprolite, the Eagle Creek above it - which is thin in this area and absent from some parts of it - and the Yakima Basalt all dip 2° to 8° south in this area. The load of Yakima Basalt and overlying olivine basalt is great, 2,000 to 4,000 feet in most places. It seems likely that the great weight of overlying basalt is squeezing the saprolite mud updip toward the north, and forcing it to escape beneath the talus and landslides that spill down from the high cliffs. Here it may form a hidden wedge which is rafting the overlying talus downslope, or it may be heaving it up in broad, flat-topped pingo-like hills. Such movement would be rather similar to that of the Gatun slides in the Panama Canal which caused rise of the floor of the canal without marked caving of the sides.

PLEISTOCENE GEOLOGY

Complicated fills, recording many different Pleistocene and Holocene events, block the mouth of every major tributary of Columbia River in the gorge. Some, like the mudflow and slurry flood deposits from Mount Hood that fill the lower Hood River Valley, are chiefly from one source; others are much more complicated. Some include fills that were built upstream into tributaries of the Columbia River by the Spokane (Missoula) Floods. Ash falls, perhaps mostly from Mount St. Helens, are abundant in these complicated fills.

The Pleistocene and Holocene deposits have not been investigated. If one should wish to start such an investigation, probably the most rewarding area would be farther to the east, perhaps in the stretch of Columbia River between Mosier and Pasco. In the Gorge, undisturbed sections of the Pleistocene rocks are rare; they are generally buried under talus, deformed by slides, or ripped to pieces by the Spokane Floods.

INTRUSIVE ROCKS

Intrusive rocks in the Columbia River Gorge are numerous and varied, but have not been studied in detail. Most conspicuous are the large stocks at Wind Mountain and Shellrock Mountain (Figures 7 and 10, and Stop 1-8). These are of hornblende-pyroxene quartz diorite. Two similar stocks occur at the head of the Wind Mountain landslide; many other stocks crop out in south-central Washington, as well as still larger masses such as the Spirit Lake, Bumping Lake, Tatoosh, and Snoqualamie batholiths. Southwest of Mount Hood are the Still Creek and Laurel Hill intrusives.

Figure 12. Ortley anticline, where transected by Columbia River east of Lyle.

Vents for olivine basalts, ranging from the striking Beacon Rock plug (Figure 11) to small dikes in cinder cones, are scattered through the area. Plug domes of andesite-dacite rise in the tops of Mt. Defiance (Figure 7) and Starvation volcanoes; both of these vents had earlier contributed olivine basalt to the complex that dammed the Columbia at Hood River (Figure 8).

Other small stocks and plugs in an area near Cascade Locks resemble cobbles of lava found in the Eagle Creek Formation, but not enough work has been done to establish this correlation.

Many plugs, sills, and dikes occur in parts of the Ohanapecosh Formation but mostly in areas several miles north of the gorge. They range from altered gabbros to silicified dacite porphyries and probably record several episodes of igneous activity.

STRUCTURAL FEATURES

Major structural features which cross the gorge are the Ortley anticline (Figure 12), the Bingen anticline, and the Mosier syncline between them. All three trend northeast in the gorge, but swing around to a nearly easterly direction when traced farther east. The Ortley anticline shows two periods of deformation, one which folded Yakima Basalt and Ellensburg Formation, but not the Dalles beds which are banked against its south flank. The later deformation caused an en echelon offset of the fold to the east, and the rise of this fold deformed the Dalles Formation. These anticlines probably started to grow during the later stages of Yakima Basalt extrusion, for the Pomona flow thins and tapers out against both flanks of the Mosier syncline.

Some reports on the gorge record the presence of a Dog Mountain anticline just west of the crest of the Cascades. This structure is not truly an anticline, but it looks like one from across the river because a slight warp in a southward dipping homocline has been undermined by Columbia River in such a way that apparent dips appear to define a broad anticlinal crest.

Hood River Fault

This major normal fault has been traced with en echelon offsets, from 15 miles northeast of Hood River (where it disappears under younger lavas) to near Bend in central Oregon, a distance of approximately 200 miles. Like all faults in this part of the range it is antithetic - the downthrow lowers the crest of the range. Over 1,000 feet of throw is present on the east side of the Hood River Valley. About 40 feet of breccia occupies the fault trace on Neel Creek. Several small cinder cones and shields are on the trace of the fault, including White Salmon volcano (Figure 8) and the large shield volcano and caldera of Monte Cristo Range.

Small faults with approximately the same trend are present at Cooke Hill and on Perham Creek.

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ROAD LOG (First Day)
Portland to Hood River

MILES

0.0 Broadway and Montgomery Street, Portland, Oregon. Drive south on Broadway; at 0.3 enter Freeway and thereafter follow signs for Interstate 80 N, east toward The Dalles. At 0.8 cross Willamette River on Markham Bridge, stay in right lane marked for The Dalles.

8.2 Rocky Butte, a post-Troutdale olivine basalt volcano on left; numerous quarries on its sides obscure undermining produced by the Pleistocene Spokane Floods.

17.3 Bridge over Sandy River. On right, at top of bluff, note a filled lava tube in flow-units from Chamberlin volcano, a post-Troutdale shield of olivine basalt that occupies much of the divide between Columbia and Sandy Rivers near their junction.

24.1 Take Rooster Rock State Park exit, cross Interstate 80 N, turn left, and follow the road to the end of the west parking lot, near rest rooms. Bus unloads here, then proceeds on to the boat landing at 25.2.

25.2 Stop 1-1. Crown Point and Rooster Rock

Crown Point (See Figures 1 and 6) is a remnant of a thick intracanyon flow of Late Yakima petrographic type, which filled an early ancestral canyon of Columbia River to a total thickness of nearly 700 feet. In the face of the bluff, the lower 130 feet of the fill is stratified palagonite tuff, carried westward and foreset bedded by the ancestral Columbia River. Lava then advanced onto the hyaloclastic fill, piling up quickly in a series of flow-unit tongues to a thickness of 555 feet. Water ponded on the sides of the lava fill against the old canyon wall arrested some of the molten tongues as pillow lavas (seen tomorrow at Stop 2-7), but on the face visible from here the entire thickness of lava congealed as one cooling unit with an 80-foot basal collonade, and a very thick (475 feet) hackly entablature. Both collonade and entablature show fan jointing - characteristic of lavas that cool with wet feet.

Rooster Rock is a landslide of a portion of the Crown Point intracanyon fill. You can see the scar from which the slide came on the cliff above. Note rotated bedded palagonite capped by fan-jointed columns and hackly entablature in the slide. Several jumbled blocks are present. Rooster Rock itself is a spire from the entablature.

26.2 Return to Interstate 80 N and continue east. High bluffs of Yakima Basalt on right, unconformably overlain by Troutdale gravels, which are capped in turn by olivine basalt flows from Larch Mountain and Pepper buttes. Across river at Cape Horn are three flows of Yakima Basalt which make an excellent stratigraphic marker. Troutdale gravels cap the Yakima Basalt unconformably, and are overlain in turn by lavas of the small Mt. Zion olivine basalt shield.

32.6 Multnomah Falls on right. We will stop here tomorrow. Across the river (left) Fletcher Flat and Archer Mountain are outliers of Yakima Basalt, their south ends obscured by talus and landslides.

35.0 The base of the Yakima Basalt should appear at about river level here but is drowned beneath talus, fans, slides, and river-terrace deposits. Fragments of Eagle Creek Formation are found in this surficial debris, but the first good outcrops of the Eagle

MILES

Creek are at McCord Creek. Across the Columbia you catch occasional glimpses of Beacon Rock, an eroded olivine basalt plug which rises more than 800 feet above river level.

39.0 McCord Creek; 250 feet of Eagle Creek volcaniclastic sediments are exposed beneath the base of Yakima Basalt at Elowah Falls.

40.7 View Stop (do not unload bus). The south end of Hamilton Mountain, across Columbia River, exposes a cross section of an ancient canyon cut into the Eagle Creek Formation and filled by a flow of Yakima Basalt (refer to Figure 2). Farther upstream is the first view of the Bonneville landslide, and glimpses of Bonneville dam can be obtained from around the next bend.

42.6 Eagle Creek; the type locality of the formation.

44.6 Take Cascade Locks exit and cross the Columbia on toll bridge.

45.6 Junction with Washington Highway 14 (U S 830 on topographic map); turn right. You are now skirting the toe of the Bonneville debris flow. Note hummocky ground, and the jumble of rocks from different formations in the slide. As you pass Ash Lake (46.7 miles) you have a good view of the cliffs forming the scarp at the head of the landslide.

47.4 Stop 1-2. Eagle Creek Formation
Examine the large block of Eagle Creek Formation perched on edge at railroad track and others in the road cut. What kind of rock makes the boulders? What is the matrix? What forms the cement? How do you account for its bedding?

47.7 Stop 1-3. Overview of Bonneville Debris Flow (see Figures 8 and 9).
The sole of the debris flow is a saprolite at the unconformity between Ohanapecosh Formation and overlying Eagle Creek. Rock falls and landslides peel off from the cliffs of vertically jointed Eagle Creek and Yakima Basalt at the head of the slide and then glide slowly toward its toe. The unconformity slopes SSW at 2° to 8° (see Figure 9). Note the second unconformity between Eagle Creek and Yakima Basalt at Greenleaf Peak (Figure 9).

48.0 Town of Stevenson; outcrops of Ohanapecosh equivalent begin at east edge of town.

50.7 Stop 1-4. Part A: Ohanapecosh Formation Equivalent
A typical outcrop of the Ohanapecosh as it is developed in the Columbia River Gorge. Identify the zeolites, the green and blue-green alteration products, the material that makes up the white veinlets. Walk forward to bus which has moved 0.1 mile to east.

Stop 1-4. Part B: Ohanapecosh Puzzle
Many outcrops of Ohanapecosh rocks are ambiguous. What are the different rocks in this outcrop, and how are they to be interpreted structurally and petrologically? Are you absolutely sure of your interpretation?

51.4 Take Carson turn off (left). The bus climbs onto the fill of olivine basalt in the Wind River valley. These basalts came from the Quaternary shield volcano at Trout Creek Hill (Figure 8).

MILES

52.1 Bus will let anyone off who wants to collect additional (and different) zeolites from those at Stop 1-4. It then proceeds one football field farther to Stop 1-5.

52.2 Stop 1-5. Wind River Lava (south edge of Carson)
Collonade and entablature of an olivine basalt flow in roadcut. Note olivine phenocrysts and phenocryst clots. One block ahead note vertical joints in the highly vesicular top of same flow. Similar lava occurs across Columbia River in the mouth of Herman Creek and in patches as far west as Cascade Locks. (See Figure 8.)

52.4 Turn right (east) at yellow blinker in Carson, and after crossing valley turn right (south) at St. Martins Junction.

53.0 Stop 1-6. Wind River Delta Sand, and Wind River Lava
Note cross-bedding, explain its origin, and the direction of foresets. These relations are clearer at next stop. Note Wind River olivine basalt at lower end of roadcut.

53.5 Rejoin Highway 14 half a mile ahead, turn left.

54.9 Turn left onto quarry road.

55.2 Stop 1-7. Wind Mountain Sand Quarry
Deltaic deposit built into a lake in Columbia valley dammed by the Wind River flows. Note cross-bedding and nature of particles that make the sand. Log in deposit gave age greater than 35,000 years by radioactive dating. Lower (south) margin of the delta has been cut off, and has received deposits from the Spokane Flood.
Return to Highway 14 (at 55.4), turn left (east).

56.3 Stop 1-8. Wind Mountain and Shellrock Mountain Stocks
Hornblende-pyroxene quartz diorite. Three stocks are visible from here, two more are 1½ miles north of Wind Mountain. A north-south linear band of these stocks, plugs and sills ranging in age from 13.4 to 7.8 million years runs the full length of the Cascades. Many breached the surface, and are the source of the andesite-dacite debris that forms the volcaniclastic rocks of the Ellensburg and of the Dalles Formations. Note the strong platy jointing at margins of the stocks and the rings of talus around them. Basalt hornfels is found at the edge of the Wind Mountain stock on the north and east; a mild hydrothermal alteration (argillization of glass and mineraloid, and filling of cavities with opal) pervades the Yakima Basalt out to about 1 mile from this group of three stocks.

57.4 Turn left onto Bergen Road, which traverses the active Wind Mountain landslide. Note bumps and displacements on road; and the "drunken forest" on either side.

57.9 Stop 1-9. Wind Mountain Active Landslide
(Junction of Bergen and Girl Scouts Road). Note effects of landslide on former pavement, on forest, and on house. Note a chunk of red saprolitized Ohanapecosh among the jumble of different rock types in the road cut. Turn around and return to Highway 14 (58.4 miles), turn left.

59.8 Yakima Basalt on left, and in the big bluffs across the river, rests on Ohanapecosh equivalent. The Eagle Creek Formation has either pinched out or (less likely) been eroded. The unconformity at the base of the Yakima crosses Columbia River just upstream from the Wind Mountain - Shellrock stock, and upward drag on the east margin of the Shellrock stock brings a small patch of Ohanapecosh (converted to hornfels) above river level on the Oregon side.

MILES

62.8 Two interbeds between Yakima Basalt flows can be seen on left, about 100 yards west of the bridge over the mouth of Little White Salmon River.

63.4 Stop 1-10. Drano Lake
Unconformable relations of lavas from Underwood volcano, and of "The Big Lava Bed", to the Yakima Basalt are well shown. Fault on Cook Hill.

64.5 In the roof of the second tunnel, the westward tilted entablature of a thick Yakima flow indicates that the direction of flow was westward.

68.0 After passing sawmill at Hood, note that the unconformity between Yakima Basalt and Underwood lava is marked for more than a mile by pillow lavas, indicating that here the basal Underwood lavas were pouring into an ancestral Columbia River.

69.1 Stop 1-11. Quartzite-bearing Gravels at Underwood
Introduction to the problem of identifying and tracing such units as "Satsop gravels", "Hood River conglomerate", "Warrendale Formation", "quartzitic gravels", and even such well-accepted names as Ellensburg Formation, Dalles Formation, and Troutdale Formation. Some of the criteria I use will be explained. What is the physical relation and the relative age of this gravel to the lavas from Underwood volcano? To the Yakima Basalt? How sure can you be?

69.4 Immediately after crossing the bridge over the mouth of White Salmon River, note stratified palagonites and pillow lavas in the basal flows from White Salmon volcano; the palagonite is at road level, the pillowed flow about 20 feet above.

70.7 Bridge over Columbia; stay on Highway 14.

72.2 Town of Bingen. At the west end of Bingen you cross two strands of the Hood River Fault (Figure 8) exposed only as small patches of fault breccia along the river bank. White Salmon volcano lies on one strand of the fault.
East of Bingen note (on left) the Bingen anticline, a big fold in the Yakima Basalt. You can see a good cross section through the anticline.

75.3 Approaching Locke Lake, note the huge cliff that shoves both railroad and highway into deep cuts at the rivers edge at Straights Point at 76.0 miles. It is formed by a thick series of flow units of porphyritic olivine-bearing Yakima Basalt of the Late Yakima petrographic type. Of Hoover Mackin's (1961) named Yakima Basalt members in the Vantage area, this is either the Roza, or the Frenchmen Springs, competent geologists argue about which, but clearly from its stratigraphic position it is at the level of these two units. If time permits we will stop here to see the flow units, vesicle sheets, and vesicle cylinders characteristic of this huge cliff-forming stratigraphic marker.
After you round Straights Point the first of Mackin's Priest Rapids flows comes in as a pillow lava-palagonite complex. Down the road to the east you see the characteristic black cliff of the Pomona flow slanting down toward river level.

77.6 Road enters cuts in the Pomona flow. Note characteristic bladed jointing into wedges and spear-shaped slabs (see Figure 3). We cross the axis of the Mosier syncline in about 1 mile, and then the Pomona begins to rise above road level.

79.7 Stop 1-12. Chamberlain Lake Rest Area
Discussion of basalt stratigraphy for the Late Yakima flows (see Figure 4) and of the structure of this part of the gorge.

MILES

80.5 Town of Lyle. See Figures 4 and 12 for the succession of flows above the tunnels which we enter just east of Lyle.

83.9 Stop 1-13. Ortley Anticline
Examine Roza flow at the bus stop, note phenocrysts and red weathering. The cliff section directly above bus shows the Priest Rapids flows, then Pomona, then volcaniclastic rocks and conglomerates that are Ellensburg Formation equivalents. A few hundred feet to the east this section turns up to a vertical position and a thick succession of Yakima flows of normal petrographic type are exposed beneath it from here to the axis of the Ortley anticline. Questions: 1) Is this an anticlinal limb or a fault? 2) By what mechanism can basalt flows be sharply flexed or folded? 3) What is the origin of the vertical walls of breccia above the road? 4) Where is the continuation of this structure on the opposite side of the river, and does it occur at the same stratigraphic level as on this side?

END OF TODAY'S TRIP Return to bus, retrace our route to the Hood River bridge, cross on it to the Oregon side. The Hood River Inn, where we will spend the night, is immediately to the left after you cross the toll bridge.

ROAD LOG (Second Day)
Hood River to Portland

MILES

0.0 Hood River Inn. From parking entrance of the Inn note the profile of Underwood and White Salmon volcanoes - each is a lava shield, with part removed by Columbia River. White Salmon shield is capped by a cinder cone. Note the "War Bonnet" (a filled lava tube) in one of the flows at the brink of White Salmon cliff. A white house is perched on it. Underwood Mountain is capped by a complex spatter rampart from a dike, which, during the closing phases of eruption, culminated in three cinder cones.
Take Interstate 5 West, bypassing the town of Hood River. The Hood River valley is filled with slurry flows and mudflows originating on Mount Hood, but these are notwell exposed on this highway.

2.4 North Hood River Interchange. Flows of Quaternary olivine basalt showing excellent coarse diktytaxitic texture and vesicle cylinders are exposed here.

3.2 View Stop (do not unload) to see a spiracle in the base of a Quaternary olivine basalt flow at the point where it crossed a small creek. The creek reformed in its old channel after the flow congealed, and now emerges into the roadcut as a spring.

3.8 Stop 2-1. Pillow-palagonite Complex
Quaternary olivine basalts pouring into ancestral Columbia River from two directions produced this complex. They, along with other flows spreading north from centers near and east of the town of Hood River, plus other flows moving south from Underwood and White Salmon volcanoes on the north side of the river, probably created a temporary dam in the Columbia at this point. Very likely the abundant particles of basalt glass

MILES

sand and silt which are such important constituents of the matrix of the Troutdale gravels were derived from these and other flows that were quenched and granulated as they entered the ancestral Columbia.
Note how direction of flow, and amount of later deformation, is indicated by the fore-set bedding of pillow lava-palagonite complexes (Fuller, 1931).
Note examples of hollow pillows, drain tubes in pillows, pillow breccias, and pillow streaks. Note, also, how a thin rind of diagenetic palagonite has formed on the sideromelane selvage of the pillows, and that even the yellow breccia matrix is mostly bits of granulated sideromelane glass with a thin rind of palagonite.

7.0 View Stop (not enough room to unload bus).
Weather permitting, the relations across river, seen yesterday at Drano Lake, can be reviewed here.

12.0 Rounding Shellrock Mountain stock. No room for a stop.
Note huge talus piles crowding highway toward river. Because of abundant joints, the Pliocene to late Miocene intrusive masses of the Cascade Mountains are nearly always surrounded by talus, or covered with felsenmeer.

13.0 Highway is heaving upward. Removal of many thousand cubic feet of material on slope above highway has not relieved this problem. Between Shellrock Mountain and Dodson the Highway Department has encountered much difficulty of this kind, probably because of the presence of the Ohanapecosh saprolite just beneath the surficial cover of talus and other debris at the base of the great cliffs of Yakima Basalt. This problem will be discussed (with maps) at the lunch stop; there are no suitable turnoffs to demonstrate it from the Highway.

17.1 Take Forest Lane - Herman Creek turnoff.

17.2 View Stop (at stop sign, just before entering underpass).
Government Point stock, a possible feeder of the Eagle Creek rocks. A smaller mass, with columnar jointing, possibly the remnant of a sill, is exposed alongside the highway half a mile east, and several more occur within an area of about 3 square miles.

21.0 Town of Cascade Locks; rest stop. The town park is at the site of the old locks built to get boats over the rapids where Columbia River is crowded south by the Bonneville landslide.

23.4 Tooth Rock Tunnel. Bonneville Dam on right.

27.5 Good exposures of Eagle Creek Formation in roadcuts.
Views of Beacon Rock across river.

29.1 Take Scenic Highway at Interchange. Saint Peters Dome rises high on the cliff at left.

30.8 Stop 2-2. Horsetail Falls
The falls dash over the entablature of a very thick stratigraphic marker flow, possibly the basal flow of the Yakima Basalt at this locality. A little of the collonade of the next flow above can be seen at the top of the falls.

31.1 Stop 2-3. Oneonta Gorge
Here a waterfall has retreated through two hackly entablature-like units forming a narrow box canyon. Traced eastward, these two flow units merge into one hackly

MILES

entablature, with the upper unit pushing westward over the lower one on ramps. At the west end of the abandoned bridge note tree molds in the base of this flow. John Allen (undated, p. 14) found 65 tree molds along the base of this flow, all of which are aligned "generally east-west". Combining Allen's observations with the ramp structures just seen, we infer that this flow came from the east.

33.4 Stop 2-4. Multnomah Falls
Refer to Figure 5 for details of the face of the waterfall. Note particularly that 15 feet of the basal collonade of a thick flow forms the top of the falls, and that a pillow lava is the next unit below this collonade.

33.9 Wahkeena Falls. (View of cataract, but do not unload bus).

35.9 Cookey Falls quarry. The specimen of Yakima Basalt known as BCR-1, used extensively as a standard by chemical analysis laboratories, was collected from the west floor of this large quarry.

36.4 Junction; stay left, on the Scenic Highway.

38.0 Stop 2-5. Sheppards Dell
The flow here is typical of a group of three, each with a huge entablature. The three form an excellent stratigraphic marker throughout this part of the gorge. They are near the base of the Yakima Basalt. The Late Yakima flows that we observed yesterday do not occur in this part of the gorge, except for the one intracanyon flow at Crown Point, which chemically seems to resemble Mackin's Priest Rapids member but may be from a different source.

39.2 Stop 2-6. Latourell Falls
Near the base of the falls a bed of boulder conglomerate is exposed, evidently the channel deposit of a swiftly flowing river. The collonade resting on it shows fan jointing - characteristic of basalt flows chilled by wet feet. The flow below the conglomerate, exposed in the rapids downstream from the falls, has distinctive phenocrysts which aid in tracing it laterally.

41.1 Stop 2-7. Pillow Lavas in a Tongue from the Crown Point Intracanyon Flow.
West of Latourell Falls the Scenic Highway begins to ascend to Crown Point in a series of loops which coincide from place to place with the old canyon wall against which the Crown flow banked. Pillowed tongues from this flow can be seen at intervals along the road. This stop is made at the point where the pillow structure is most obvious because it has been brought out by weathering. Refer to Figure 6 for a schematic diagram of the inferred relations of these pillowed tongues to the old canyon wall.

41.6 Crown Point Vista House. If the day is clear we will stop here for the exceptional view; particularly for the relations - well shown across the river - of the three thick basal Yakima flows at Cape Horn to the Troutdale gravels, and to the lavas from post-Troutdale Mt. Zion volcano. Up river, Archer Mountain and the attendant landslides at its base are clearly visible; Beacon Rock and Bonneville Dam can be seen in the distance. On the Oregon side, the north-sloping horizon above the great Yakima Basalt cliffs is the surface of the large Larch Mountain shield volcano. The two rounded bumps closer to us are satellitic cinder and lava cones (Pepper Mountain and an unnamed butte to the south) on the flank of the Larch Mountain shield.
Downstream the view is less inviting. The pulp mill at Camas and the aluminum plant at Troutdale change the air to miasma. Geologically the Troutdale gravels and flows

MILES

from olivine basalt vents, mostly younger than the Troutdale, dominate the landscape. The Boring Lava of Willamette Valley east of Portland is part of these. The base of the Troutdale gravels rests on successively younger Yakima flows on the south side of the river; this relationship can be traced eastward in the headwaters of tributaries of the Columbia River where Troutdale gravels lie beneath the lavas of Larch Mountain.

42.0 Stop 2-8. Olivine Basalt Flow
Interstratified with Troutdale gravels and sands. Note the high percentage of weathered sideromelane glass in the sands and also interesting features along the basal contact of the lava. Note cross-bedding and shingling, indicating transport to west.

42.8 Stop 2-9. Portland Women's Forum State Park
Another excellent view point "Dedicated to the preservation of the natural beauty of the Columbia River Gorge." Also known as Chanticleer Point. Striking view of Rooster Rock. The history of these names and the interesting erosion of fence railings will be discussed.

44.4 Corbett Junction, keep left.

45.2 Bell Road Junction, take Bell Road to right, as it is a shortcut.

46.2 Rejoin Highway at stop sign. Numerous cuts in Troutdale gravels beyond this junction.

48.1 Stop 2-10. Troutdale Gravels (Stop at bend, left side of road)
Cobble components: How many different kinds of rocks are present, and roughly in what proportions? Are the basalt cobbles chiefly from Yakima flows, or chiefly from the young olivine basalts such as produced the lava dams at Hood River and upstream from Cascade Locks? What are the chief components of the sand layers? What criteria can you find in the outcrop indicating direction of transport? Is the dip of the major bedding primary, or has the formation been deformed?
The sand in Sandy River is not from the Troutdale Formation, but from a mudflow off Mount Hood less than two hundred years old.
Continue to the base of the hill, do not cross bridge (at 50.3 miles) into the town of Troutdale, but turn right through the State Park, and take Interstate 80 N into Portland.

FIELD TRIP NO. 5

URBAN ENVIRONMENTAL GEOLOGY AND PLANNING

PORTLAND, OREGON

BY

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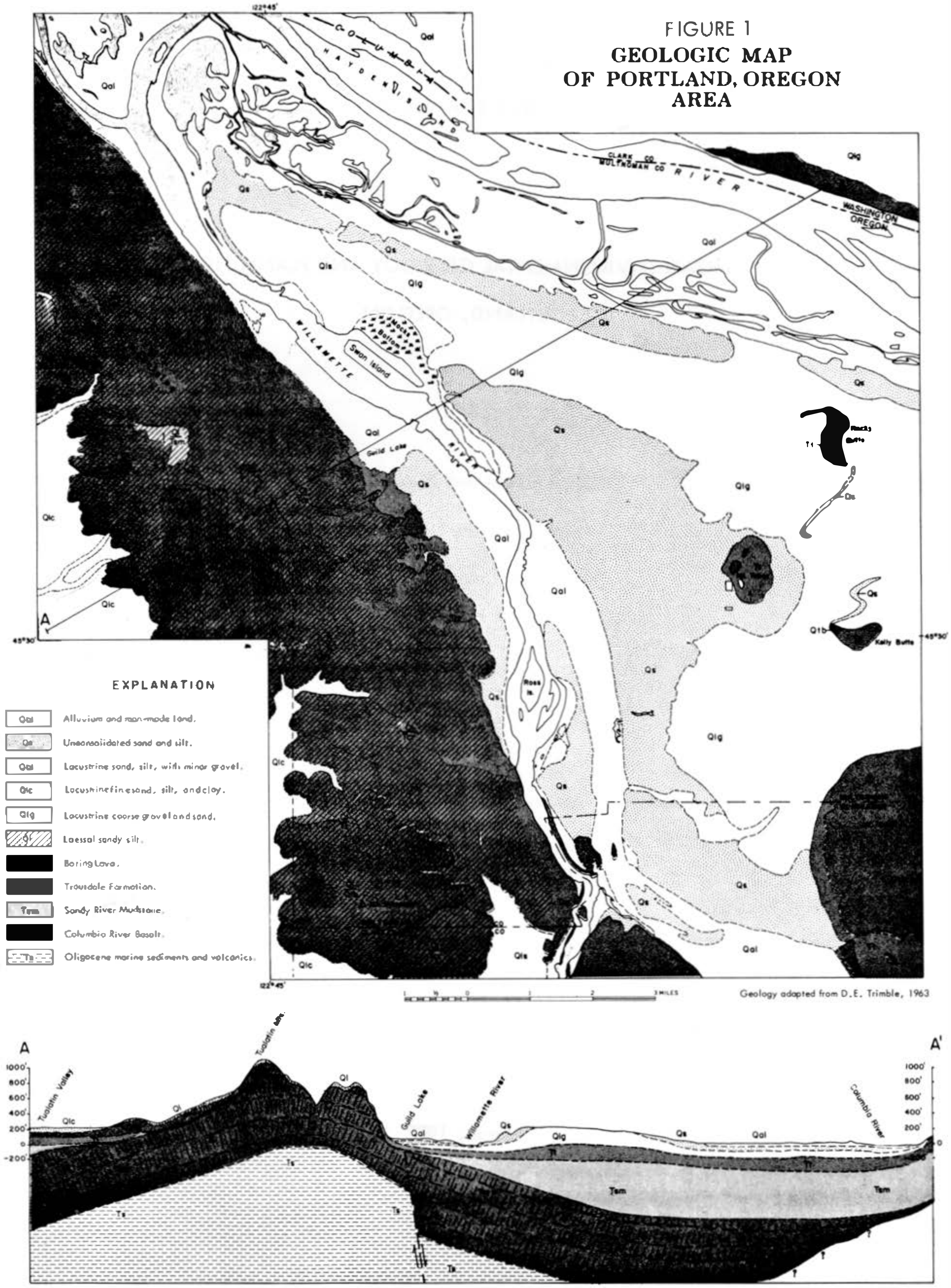
Portland State University

Portland, Oregon

March, 1973

FIGURE 1
GEOLOGIC MAP OF PORTLAND, OREGON AREA



URBAN ENVIRONMENTAL GEOLOGY AND PLANNING, PORTLAND, OREGON

INTRODUCTION

The Portland city one-day field trip is oriented toward urban environmental geology and planning. The trip will examine the geologic conditions in which the city is situated and will encourage discussion of zoning, legislation, and building codes.

Included in the tour will be a general review of the local geologic history and stratigraphic units. The morning will be spent examining the West Hills area, including review of the history and treatment of the Zoo landslide, residential areas on creeping soil, planned unit development design for a steep canyon area, and mudflows and landslides in developing areas.

After lunch at the Hillvilla Restaurant, perched high on the hill overlooking the river, the evidence for the Portland Hills fault will be reviewed. Sand and gravel supply from rivers and pits will be observed in terms of zoning and conservation. Modern flooding in terms of urban growth will be viewed.

ENGINEERING GEOLOGY

The geologic setting in Portland is shown on the map and cross section (Figure 1) and the cover photograph. The major part of the city overlies fluvial-lacustrine sands, clays and gravels in broad terraces 100 to 200 feet in altitude. West of the river and the terrace lands, the Columbia River Basalt is warped in northwest-trending en echelon folds, the easternmost one of which may involve fault displacements. Boring lava has erupted in numerous small volcanoes throughout the Portland area. Deeply weathered residual soils and loessal sandy silt cap the West Hills anticline above the 400 foot elevation. In many areas these surficial deposits are involved in landslides and soil creep. Engineering characteristics of the geologic units are shown in Figure 2.

The Portland area provides a variety of examples of geologic conditions significant to urban growth. The urban geologic setting is generally favorable for construction materials, water supply, waste disposal, transportation routes, and foundations. However, in some areas natural conditions require individual studies to adapt structure and building locations to unstable ground, flooding, and potential seismic hazards. Locally, landslides, earth flows, and possible fault lines indicate need to accommodate building to the geologic situation. Special zoning or building restrictions may be needed because of geologic hazard and the regulation of the resources. A mechanism or system such as grading-code requirements could be effective in improving the application of engineering geology to urban environmental problems.

At the present time the construction of small structures and residential urban expansions generally proceed without benefit of geologic studies.

Incomplete information on the types and distribution of hazards is a detriment in delineating areas where engineering geology studies are needed. Methods of compiling data on damage, slopes, and other topographic and geologic features have been studied by the authors in an attempt to evaluate their merits and to delineate areas in which engineering geologic studies are needed for safety and economic saving.

Landslide damage in Portland is more common than is generally realized owing to time gaps between individual movements and to the relatively small number of people directly affected by any one slide. Public utility and road damage in Portland can amount to as much as one-third of a million dollars per year. Slides cost the Oregon State Highway Department an average of more than $400,000 per year (Schlicker, 1956). One slide south of Portland involved damages amounting to several times this amount. In all cases the damage to private properties is in addition to the cited figures.

The variety of natural conditions hazardous to Portland's population and structures will be reviewed and will serve as a basis for a discussion of the actions needed to expand the application and usefulness of engineering geologic expertise.

AGE	FORMATION	LITHOLOGY	DESCRIPTION
Pleistocene	Portland Hills Silt		Portland Hills Silt: 0-42+ feet thick. Clayey silt and silty clay; mudflows and slumps on slopes over 15%; low permeability; makes moderately strong and compressible fills; shallow perched water table in some areas.
Pliocene	Boring Lava		Boring Lava: 0-100+ feet thick. Gray olivine basalt with an expanded texture; generally solid and stable except where highly weathered or where volcanic sediments are interbedded.
	Troutdale Formation		Troutdale Formation (?): 0-25+ feet thick. Pebble conglomerate, moderately indurated; small localized deposits, usually breaks down to constituent particles upon excavation.
Miocene	Columbia River Basalt		Columbia River Basalt: 700+ feet thick. Weathered and unweathered basaltic lava flows possibly with interflow zones of ash, breccia, and/or baked soil; generally solid and stable except in steep exposures where highly weathered and where movement is possible on dipping, clayey interflow sediments.

Figure 2. Engineering characteristics of the geologic units in the Portland area, Oregon.

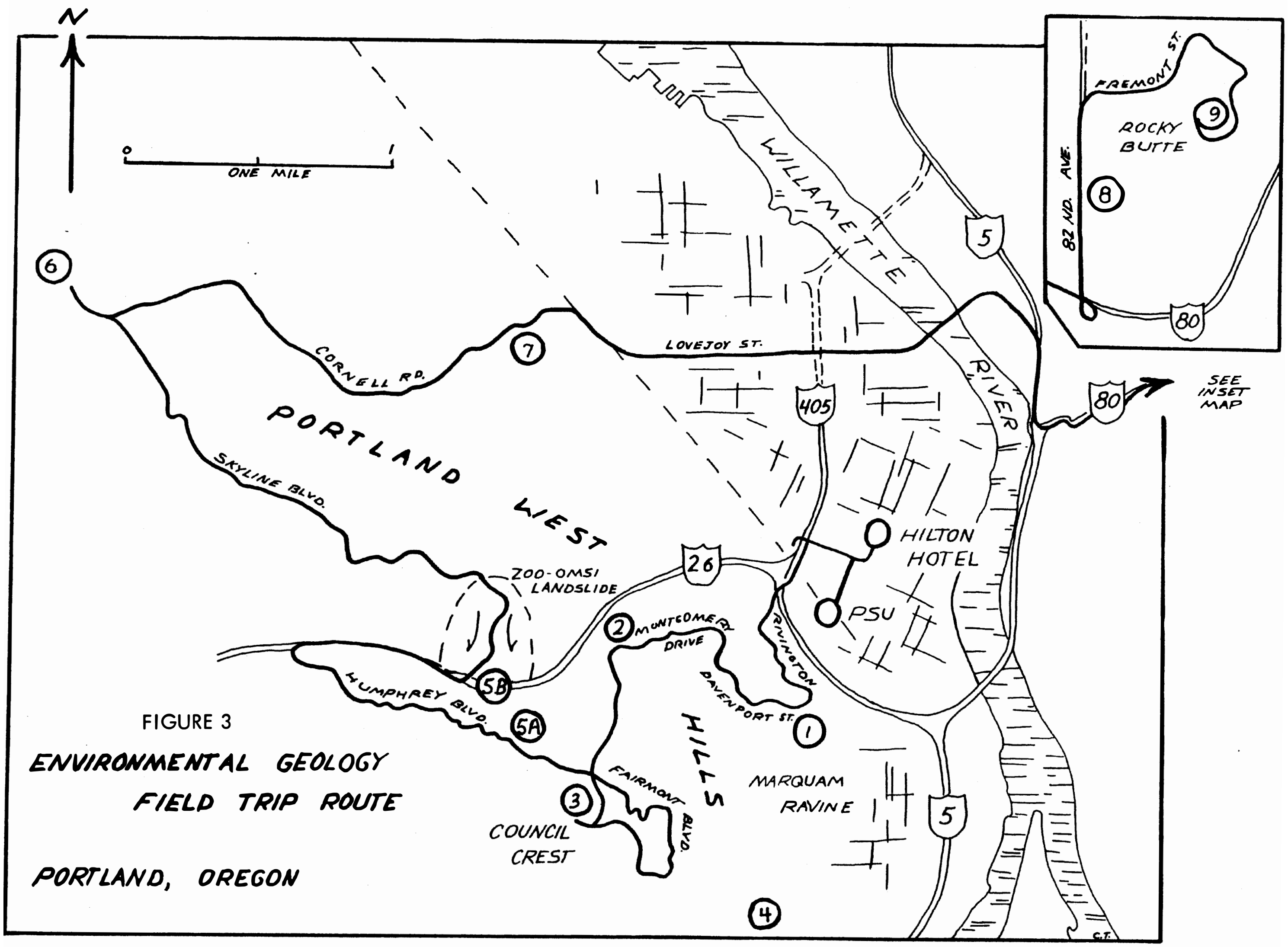


FIGURE 3

ENVIRONMENTAL GEOLOGY FIELD TRIP ROUTE

PORTLAND, OREGON

TRIP ROUTE

A sketch map of the field trip route is provided in Figure 3. An outline of the major stops follows.

START: Portland State University (Broadway and Montgomery)
(Optional in case of rain: Review of environmental maps of the West Hills and Marquam Hill area, Room S-17 Cramer Hall)

STOP # 1 - Marquam Gulch (30 min.)
Residential construction on steep slopes without control or verification of subsurface foundation conditions has resulted in extensive damage to numerous structures in the West Hills area. Planned unit development of canyon areas designed to accommodate natural conditions has been opposed by adjacent residents. Adequate public relations and consequent public cooperation is necessary to improve the use of technical knowledge.

STOP # 2 - Residential Landslide, Montgomery Drive (30 min.)
Isolated and intermittent landslide damages to individual residences incur great cost to the individual homeowners and amount to a total yearly cost which is difficult to assess, but which nevertheless is significant. Plots of the known distribution of damages indicate that slope maps may be a useful indicator of problem areas justifying engineering geologic studies.

STOP # 3 - Council Crest (Optional) (30 min.)
Overview of the city.

STOP # 4 - Hillvilla Restaurant for Lunch. (1 hr. 15 min.)

STOP # 5-A - Zoo-OMSI Overview and Landfill (30 min.)
Uncontrolled landfillings and steep hillside areas scarred by numerous landslides are planned for high-density apartment construction. Compaction, benching, or soil removal are not presently required for landfills. An overview of the large Zoo-OMSI landslide to the north can be seen from this site. Measured landslide motion of the Zoo-OMSI slide is closely related to peak winter rainfall greater than about 7.5 inches per month. (See map of slide area, Figure 4.) Most other slides are activated by heavy rainfall, suggesting surficial drainage might be one stabilizing technique.

STOP # 5-B - Zoo-OMSI Landslide (1 hr.)
Activation of the toe area of the 10-acre Zoo-OMSI landslide began in 1959 threatening Zoo and Museum properties until buttressing was completed in 1969.
The head scarp of the slide crosses the OMSI-Zoo access road just south of the entrance to the Zoo and runs westerly to the southeast corner of the OMSI building. Individual vertical displacements in the head scarp area in this locality range from a few inches to 3 feet and total displacement is nearly 8 feet. Humps and swales in the access road in front of the OMSI building as well as cracks and displaced curbs and sidewalks show movement characteristics. Since placement of the buttress in the summer of 1969, visible movement has not occurred.
The slide is wedge shaped with a nearly vertical head scarp and a nearly flat (2° to 5°) failure plane sloping south toward the highway. (See Figures 4 and 5.) The main detachment surface is the contact between decomposed basalt (consisting of stiff clayey silt) and dense crystalline basalt. Near the toe of the slide, the decomposed basalt overrides stiff gray silt of the Troutdale Formation. Within the slide mass, several internal planes of failure are present.

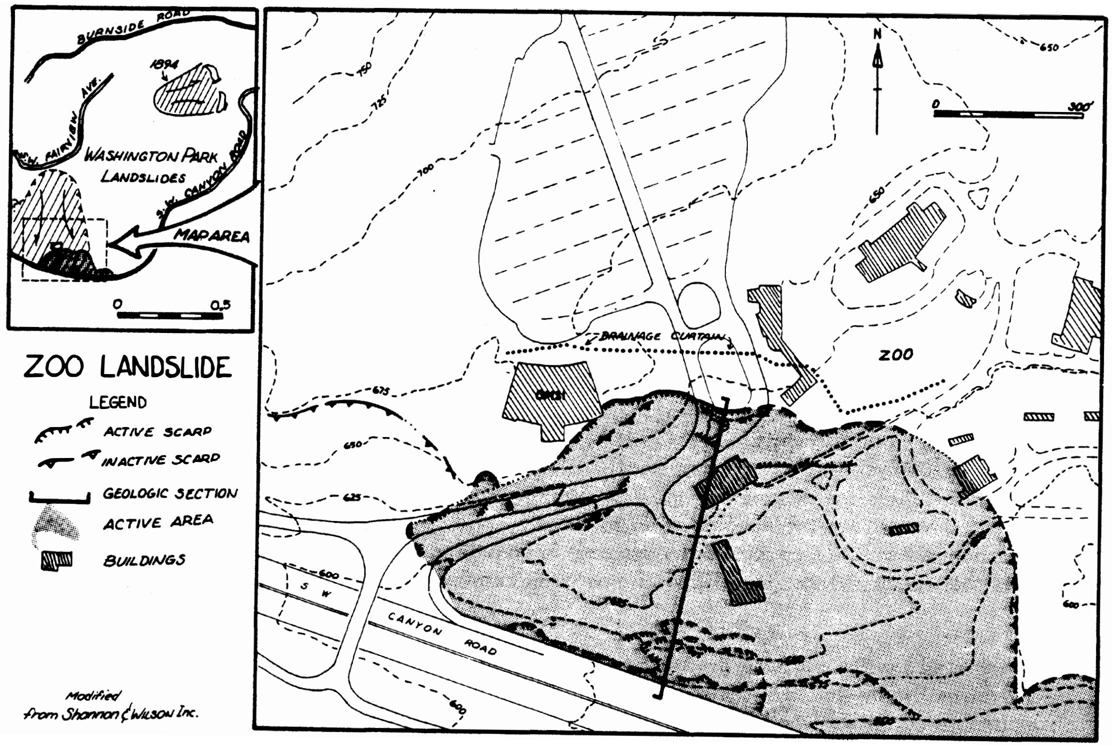


FIGURE 4

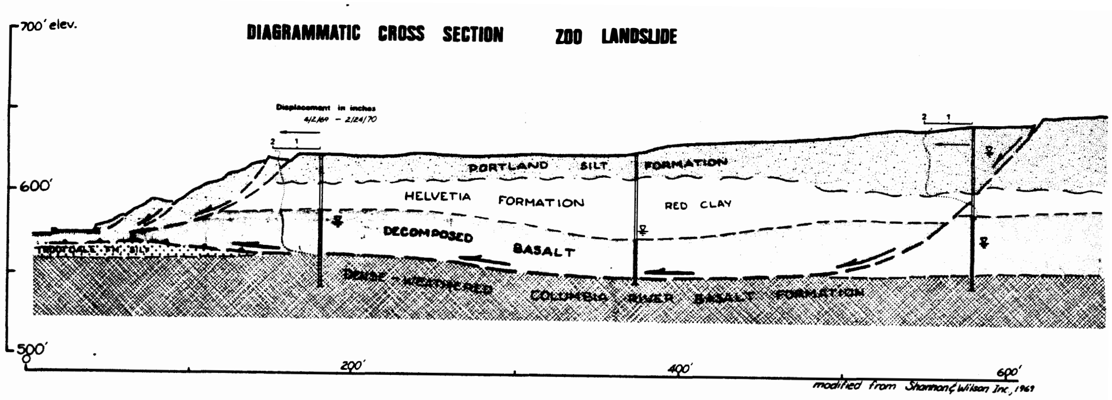


FIGURE 5

STOP # 6 - Skyline Earthflow (30 min.)

Heavy storms in January, 1969, triggered rapid flow of mixed earth, water, and vegetation down the steep gully. The flow extended about 1/4 mile narrowing from more than 100 feet at the head to about 25 feet width near the toe. This flow and other similar flows indicate that considerable life and property danger will occur along steep gullies. Better understanding of mechanisms for such flows may help recognition of potential danger areas.

The Tualatin Valley is visible to the west of this site. Engineering geologic studies (Schlicker and Deacon, 1967) have delineated the major environmental problems and their distribution.

Cornell Road - Potential hillside residential construction areas seen along the road are heavily scarred by landslide damage.

STOP # 7 - Troutdale Formation - Gravel Quarry (Optional) (25 min.)

High gravel deposits plastered against the east escarpment of the Portland Hills may represent either uplifted parts or erosional remnants of the Troutdale Formation. Hydraulic excavation and landfill on this hillside area may have had some effect on land instability and damage to residences.

STOP # 8 - Rocky Butte Gravel Quarry (30 min.)

About 20,000 years ago large runs of Missoula-flood glacial meltwater (more than 400 feet in depth) formed channels and depressions and deposited gravel (now terraced) in the Portland area. Erratic boulders were rafted by icebergs as far south as Eugene. At present, increased runoff in some of the channelways is traceable to the drainage from paving and roofs that accompany urban expansion. One abandoned channel is utilized as a railroad and freeway (I-80) route.

STOP # 9 - Rocky Butte Overview

Boring lava, which intruded the Troutdale Formation, forms numerous partly volcanic hills rising above the fluvial-lacustrine terraces of east Portland. The volcanic rock provides a source of rock aggregate construction material, but is a hinderance in terms of the development of underground utilities.

RETURN TO - Portland State University (Broadway and Montgomery)

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FIELD TRIP NO. 6

STRATIGRAPHY AND STRUCTURE OF YAKIMA BASALT IN THE PASCO BASIN, WASHINGTON

BY

Donald J. Brown and R. K. Ledgerwood

Atlantic Richfield Hanford Company
Richland, Washington

March 1973

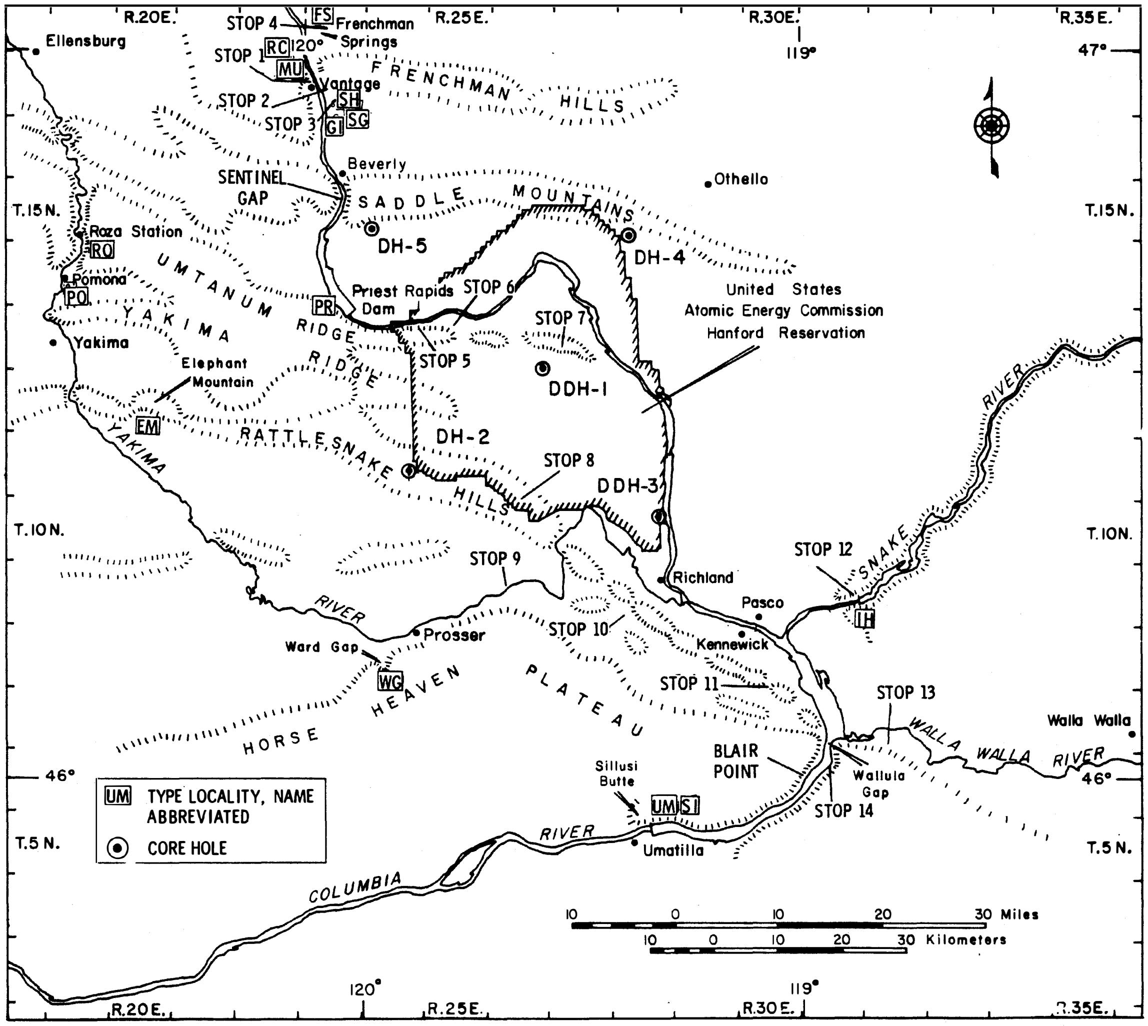

Figure 1. Map of south-central Washington showing locations of tour stops.

STRATIGRAPHY AND STRUCTURE OF YAKIMA BASALT IN THE PASCO BASIN, WASHINGTON

DISCUSSION

One of the largest accumulations of flood basalt on the earth's surface is located in the Pacific Northwest in the physiographic province known as the Columbia River Plateau. Enormous volumes of basaltic magma, welling up through fissures in the earth's crust, spread out in broad sheets one upon the other over an area conservatively estimated at two million square kilometers. The average thickness of the basalt sequence over the Columbia River Plateau is approximately 550 meters; however, the greatest thickness discovered to date is in the Pasco Basin in south-central Washington (Figure 1), near the center of the plateau. Here, an exploratory well was drilled by the Standard Oil Company of California to a depth of 3,248 meters without reaching the base of the basalt sequence.

Prior to 1960, relatively little was known about the structure and stratigraphy of the Columbia River Plateau. Exposures of the basalt sequence were poor except in deep river gorges, and in most cases access was extremely difficult or impossible. Another problem faced by the early workers was the apparent lithologic similarity of most flows. The principal characteristics used for identification and correlation of flows and flow sequences were the gross physical features such as jointing, color of weathered surfaces, or presence of large phenocrysts. Features such as these, however, seldom remain constant when a flow is traced for many miles. For example, jointing reflects the cooling history of the flow, and this varies with distance from the vent, thickness of the flow, changes in the nature of the surface that it covered (i.e., the local presence of marshy ground), whether the flow ponded quickly and crystallized mainly from a motionless liquid or whether it crept forward throughout the major period of crystallization, and still other factors.

In the region surrounding the Pasco Basin, a number of field sections were published in which the flows and flow sequences, exposed along the anticlines or in the river gorges, were named and their general physical properties described (Laval, 1956; Makin, 1961; Schmincke, 1967). Unfortunately, these field sections (which later became type localities) were up to one hundred kilometers apart (Figure 1), and their relationship to each other in the stratigraphic sequence could not be developed with assurance. The only credible correlations made were those where the flows and/or flow sequences were essentially walked out.

In recent years technological developments, primarily in petrography and geochemistry, have led to identification of a number of characteristics by which flows and flow sequences can be identified. One of the first and most significant developments made toward characterizing specific properties of the basalts of the Columbia River Plateau was the published work by Waters (1961). On the basis of petrographic and geochemical properties identified in the basalt sequence, he was able to show a major subdivision between the middle Miocene basalts and the upper Miocene-lower Pliocene basalts. These two units were given formational designations, Picture Gorge Basalt and Yakima Basalt, respectively, and the Columbia River Basalt was elevated to group status. This adopted nomenclature has provided the flexibility to accomodate the stratigraphic subdivisions which have subsequently been added.

Following Water's publication in 1961, there was a lapse of about five years before additional methods for characterizing Columbia River Basalt began to appear in the literature. Swanson (1967) provided more definitive petrographic data on the upper Yakima Basalt flows exposed near the western margin of the Columbia River Plateau utilizing primarily plagioclase/pyroxene ratios for characterizing flows. Schmincke (1967) showed that there were significant differences in chemical composition between individual flows of the upper Yakima Basalt and developed a stratigraphic section for the region surrounding the Pasco Basin. He showed a credible relationship between the upper Yakima Basalt flows which had been named and the designated type localities. Holmgren (1970) employed K/Ar age dating and paleomagnetic technology for correlating thick flow sequences of the Yakima Basalt in central Washington, and Osawa and Goles (1970) demonstrated the applicability of neutron activation technology for identifying trace element variations in and between the Picture Gorge Basalt and Yakima Basalt.

Technologies which have been used with limited success or are still being evaluated with respect to their usefulness in characterizing Columbia River Basalt should also be mentioned. McKee and McKee (1970) observed differences in refractive indices within the major subdivisions of the Columbia River Basalt Group but stated the method was not useful in distinguishing individual flows or flow sequence within a formation. Ord (1970) made a preliminary evaluation of the feasibility of using Mössbauer spectra for identifying individual flows of upper Yakima Basalt. Ord concluded that the technique needed further development before it could be applied to basalt flow identification. Characterization of Columbia River Basalts as a function of plagioclase microhardness, plagioclase structural state, oxygen fugacities, and pyroxene fractional crystallization are currently under investigation.

In 1968 the Atlantic Richfield Hanford Company, in behalf of the U.S. Atomic Energy Commission, undertook a study to develop a detailed stratigraphic model of the Pasco Basin. The initial effort was directed toward characterizing a 1,000-foot core (DDH-1) taken from near the center of the Hanford Reservation (Figure 1). On the basis of chemical composition, seven flows were identified in the core. Two core holes (DH-2, DDH-3) were then drilled in the southern part of the Reservation to determine how well, if at all, the flows identified in DDH-1 correlated with those cored to the south, a distance of about 30 kilometers. Only two of the flows proved to have unique enough chemical properties for correlation. One flow had a significantly high Ba concentration and the other had an unusually low concentration of TiO_2 and K_2O and a high concentration of Cr with respect to the other flows.

It was discovered that the two flows with unique chemical properties were exposed in the Columbia River Gorge on Sillusi Butte. These two flows were essentially walked out and sampled at several locations between Sillusi Butte and Wallula Gap (Figure 1) to determine the lateral variability in their unique chemical properties. The results of this work showed conclusively that the unique chemical properties associated with these two flows did not vary significantly with distance and that they could be used with assurance for correlating between core holes within the Pasco Basin for distances up to 40 kilometers.

One of the core holes in the southern part of the Reservation (DDH-3) was drilled to a depth of 3,540 feet. In characterizing the chemical properties of the flows in this core, it was noted that there were four additional unique flows or flow sequences present deeper than the section cored in DDH-1. Two flow sequences were unique in that they were porphyritic and could be distinguished from each other by their Cr content. Two horizons were discovered where a marked change occurred in the content of a major oxide. At one horizon there was an abrupt change in the TiO_2 content of the flows, and at the second horizon there was a significant change in the K_2O content.

On the basis of this information, additional coring was then started in the northern part of the Hanford Reservation on the south flank of Saddle Mountains. These two core holes, DH-4 and DH-5, were drilled to depths of 4,766 feet and 5,002 feet, respectively. All unique flows, flow sequences, and horizons of contrast identified in the DDH-3 core were identified in the DH-4 and DH-5 cores with the exception of the high Ba flow. A cross section (Figure 2) across the Pasco Basin summarizes the correlations made between core holes and shows the data extended to nearby canyon sections. More detailed sections of Sentinel Gap and Blair Canyon are shown in Figures 3 and 4. Partial chemical data are also provided for these two canyon sections in Tables 1 and 2. It should be noted that the marker flows and horizons of contrast occur in the same succession at each site, a feature which enhances the correctness of the correlation.

Work is now being done to correlate the unique flows identified in the core holes with type section flows in the surrounding region. Tentative correlations are shown in Figure 5.

Table 1. Selected analytical data for Sentinel Gap Section. AA and ES refer to analytical methods used.

Sample Serial Number	MgO % AA*	CaO % AA*	K_2O % AA*	TiO_2 % AA*	Ba ppm AA*	Cr ppm Es**
A1306	3.4	8.4	1.0	3.4	625	19
A1307	3.7	8.1	0.9	3.5	1936	10
A1310	5.4	8.4	0.9	3.1	557	96
A1311	4.1	7.5	1.0	3.3	593	14
A1349	5.2	8.0	1.1	3.4	677	
A1350	5.0	8.2	1.1	3.1	559	
A1351	4.6	7.8	1.2	2.8	700	
A1352	4.3	8.4	1.2	2.9	1550	
A1353	4.8	7.8	1.3	2.8	775	
A1354	4.7	7.6	1.2	2.9	735	
A1355	4.6	7.6	1.3	2.8	788	
A1356	4.8	7.9	1.2	2.7	788	
A1357	4.5	8.0	1.1	2.8	634	
A1358	4.9	7.7	1.3	2.8	808	
A1359	5.1	7.4	1.1	1.7	700	
A1360	5.4	8.1	1.0	1.8	689	
A1361	5.3	9.1	1.3	1.7	560	
A1362	5.7	9.1	0.9	1.7	565	
A1363	5.6	8.5	1.0	1.8	630	
A1364	5.6	9.3	0.8	1.9	646	
A1365	5.6	9.4	0.9	1.8	578	
A1366	5.2	8.0	1.0	1.8	606	
A1367	5.1	8.4	1.0	1.9	613	
A1368	3.8	6.7	1.4	2.0	811	

Analytical Method

*Atomic Absorption
**Emission Spectroscopy

Table 2. Selected analytical data for Blair Point Section

Sample Serial Number	MgO % AA*	CaO % AA*	K_2O % AA*	TiO_2 % AA*	Ba ppm AA*	Cr ppm NAA**
A1348	2.9	5.5	2.6	2.5	3439	
A1175	3.0	6.1	3.0	2.2	3612	11
A1176	2.9	6.4	3.5	3.1	3923	13
A1177	4.5	8.1	1.7	2.6	864	26
A1178	4.6	8.2	1.5	2.7	739	20
A1179	4.6	8.2	1.6	2.7	767	22
A1180	4.4	8.2	1.9	2.7	810	29
A1181	4.5	7.9	1.8	2.6	737	20
A1182	4.2	7.8	1.8	2.6	674	27
A1183	4.2	7.8	1.7	2.6	496	26
A1184	4.6	8.4	1.2	2.5	630	46
A1186	4.8	8.0	1.4	2.4	747	41
A1187	4.7	8.0	1.8	2.5	767	42
A1188	4.7	8.0	1.8	2.5	767	47
A1201	4.6	7.8	1.3	2.6	624	46
A1200	4.4	8.1	1.3	2.7	795	47
A1199	4.5	8.0	1.4	2.7	661	42
A1198	4.5	7.9	1.3	2.6	729	43
A1197	4.4	7.8	1.4	2.5	693	42
A1196	4.6	7.9	1.4	2.9	722	50
A1195	4.6	7.8	1.1	2.8	628	25
A1194	4.5	8.0	1.2	2.9	579	26

Analytical Method

*Atomic Absorption
**Neutron Activation Analysis

STRATIGRAPHY OF THE PASCO BASIN

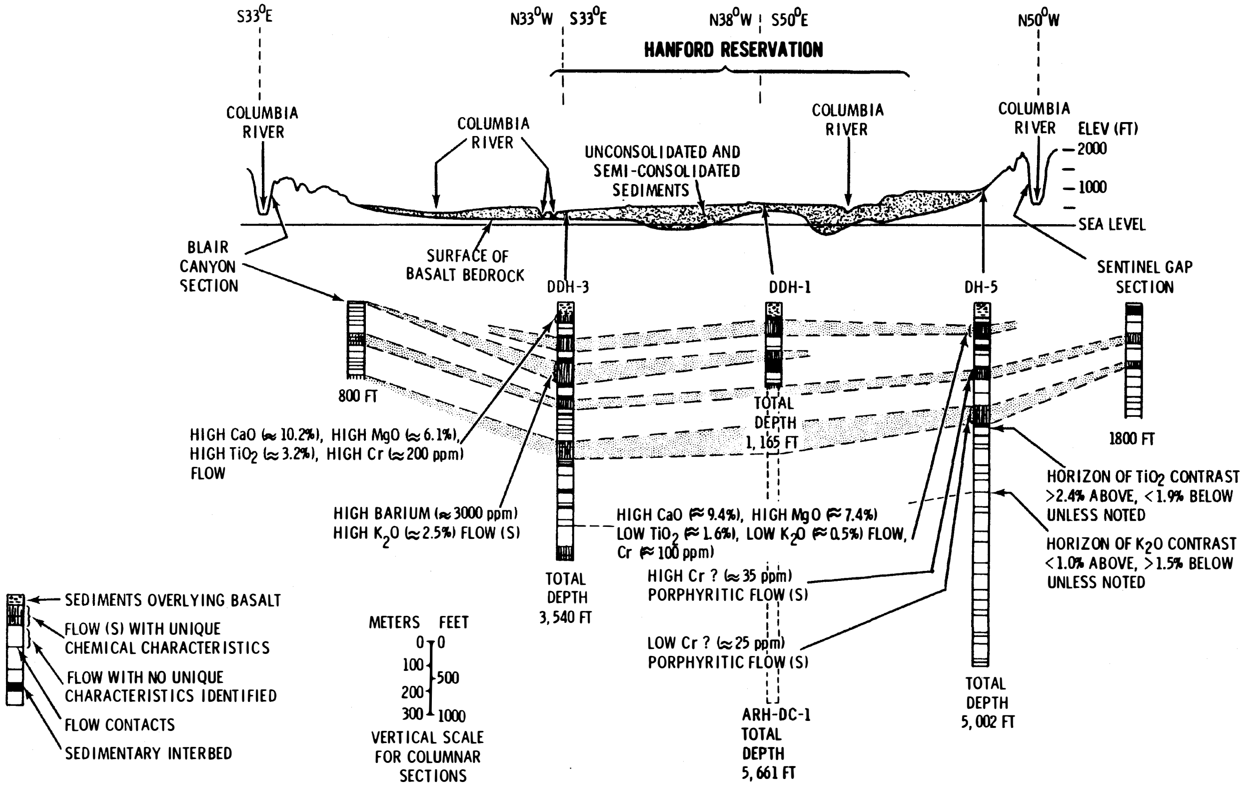

Figure 2. Generalized stratigraphy of the Pasco Basin.

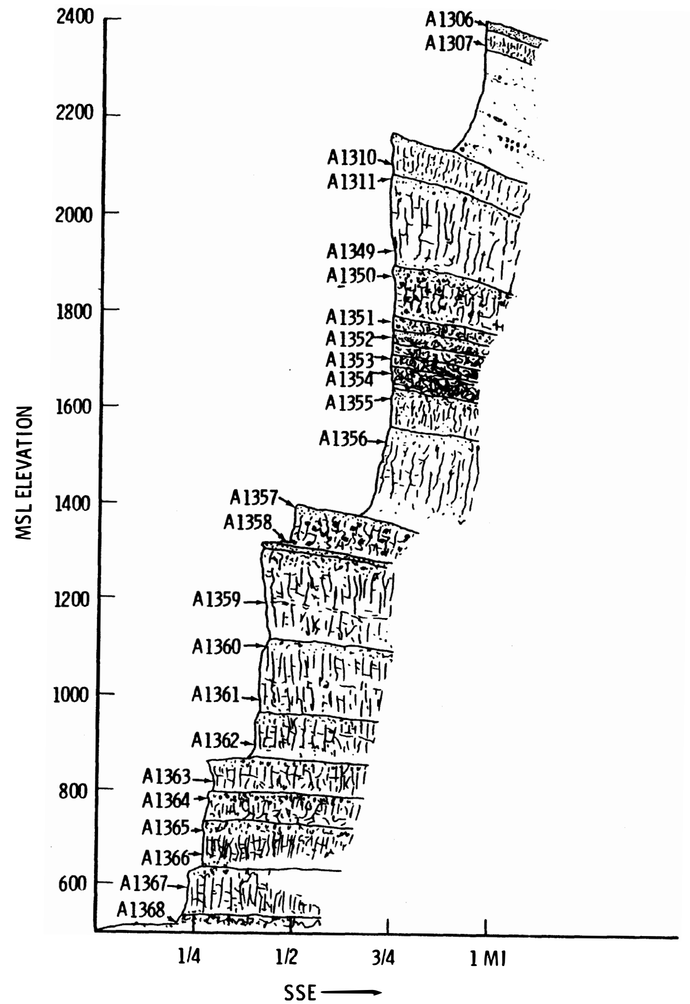

Figure 3. Generalized section of upper Yakima Basalt exposed in Sentinel Gap.

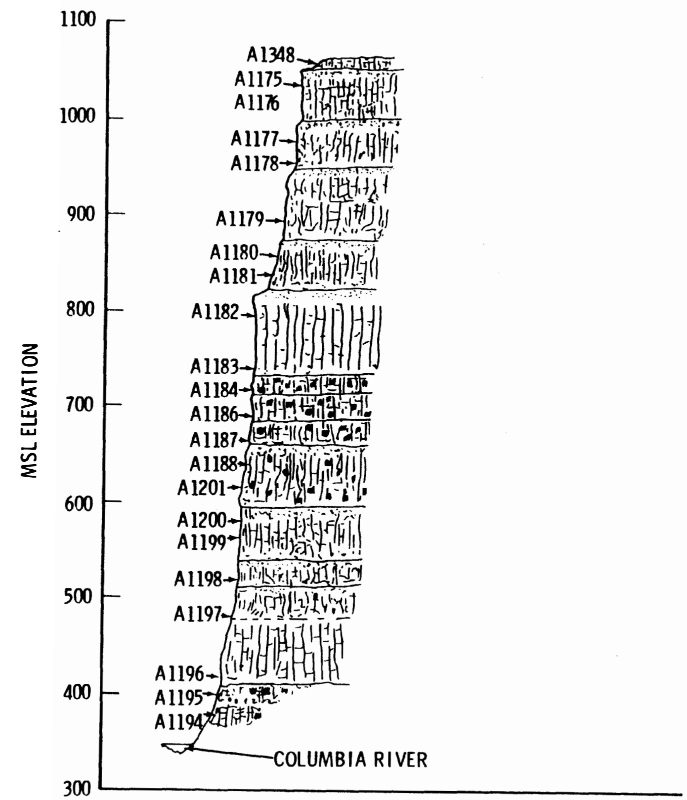

Figure 4. Generalized section of upper Yakima Basalt exposed in Columbia River Gorge at Blair Point.

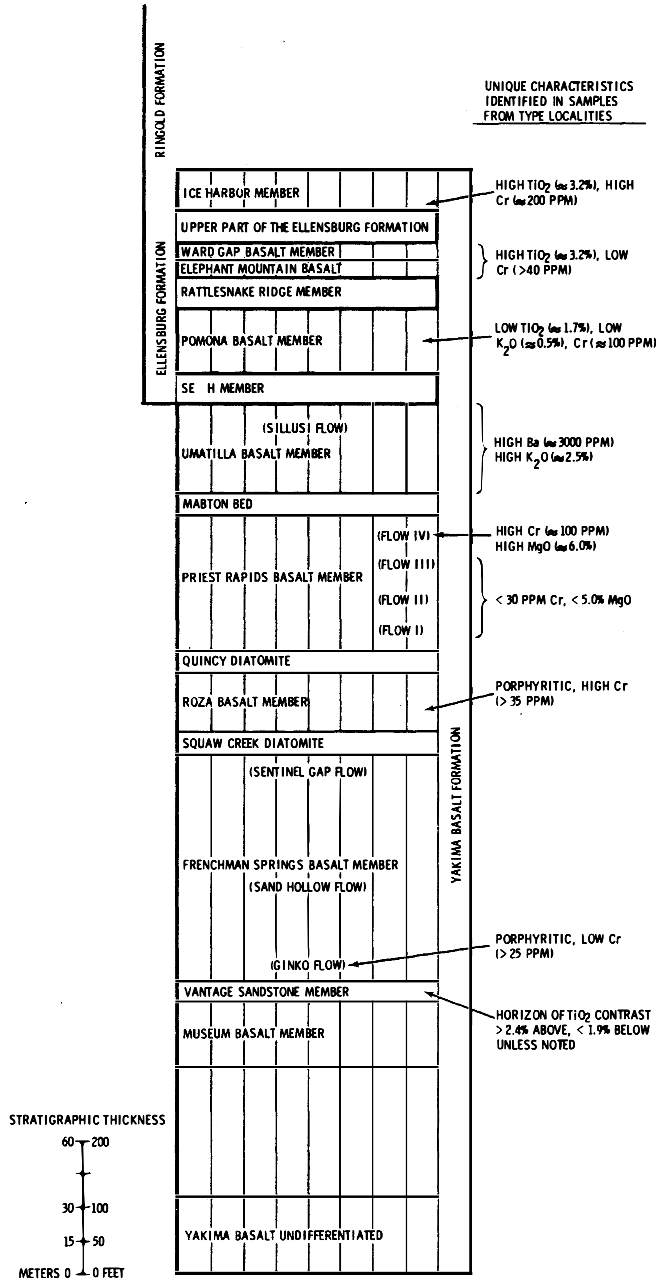

Figure 5. Stratigraphic section of upper Yakima Basalt and Ellensburg Formation.

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TRIP ROUTE

The field trip to the Pasco Basin affords the opportunity to study similarities and dissimilarities in the type section Yakima Basalt flows and some of the latest techniques developed for identification of these flows. More importantly, a number of locations can be examined where previous flow correlations have led to wrong structural interpretations.

This guide describes a tour held on Sunday, March 25, and Monday, March 26, 1973 through the Pasco Basin, Washington. Because portions of the tour are through restricted areas on the Hanford Reservation, buses and escorts are provided by the U.S. Atomic Energy Commission-Richland Operations Office. Starting point for the tour is the lobby of the conspicuous, seven-story Federal Building in Richland, Washington.

STOPS 1 - 4: The area around Vantage, Washington (Figure 1). Here, the structure and stratigraphy of the area can be observed and important physical characteristics of the flows, as described by Mackin (1961) can be inspected. The variability of these distinguishing characteristics within certain flows can also be observed.

STOP 5: The north flank of Umtanum Ridge midway between the Priest Rapids dam site and Vernita Bridge. Asymmetrical folding of the anticline, typical throughout the Pasco Basin, can be seen, especially the steeply dipping to overturned north limb. The tectonic implications of these sharp axial inflections observed at this stop are discussed.

STOP 6: Small rock quarry at the eastern end of Umtanum Ridge where Washington State Highway 240 crosses. Here a demonstration is given of a portable non-dispersive X-ray unit, which is used to distinguish chemical properties of basalts in the field.

STOP 7: Gable Mountain near the center of the Hanford Reservation. At this stop a number of sites were excavated to evaluate the tectonic significance of certain geomorphic features. The significance of the structures exposed in the sidewalls of these trenches is discussed.

RETURN TO Federal Building, Richland, Sunday at 5:30 p.m.

BOARD bus in front of Federal Building, Richland, Monday morning at 7:30 a.m.

STOP 8: Top of the eastern end of Rattlesnake Hills. From this vantage point, the lineation of hills to the southeast (Olympic-Wallowa Lineament) is observed; also, an overview of the Hanford Reservation and the extent to which the ground surface has been modified by wind erosion.

STOP 9: Near Chandler, Washington. Geomorphic features related to the purported Wallula Gap Fault are seen along the north flank of Horse Heaven Hills extending across the Yakima River toward the top of Rattlesnake Hills. Flatirons of brecciated basalt are also observed on the south flank of the Horse Heaven Hills. Their tectonic implication is discussed.

STOP 10: Near the mouth of Badger Canyon on the road from Kiona to Vista. Ash falls intercalated with eolian deposits of reworked glaciofluviatile sediments are seen in the road cuts. Also observed are numerous clastic dikes with highly complex structures. Their possible mode of formation is discussed.

STOP 11: Finley rock quarry. This quarry is located along the western extension of the purported Rattlesnake-Wallula Fault. Evidence seen in the quarry supporting or rejecting this hypothesis is discussed.

STOP 12: Ice Harbor Dam. Two short stops are made at this site. The first stop is on the north side, upriver from the dam, to observe several small feeder dikelets cutting upper Yakima Basalt (Swanson, 1967). On the south shore, and downriver from the dam, a larger dike is observed cutting several flows and merging with the flow it feeds. Evidence of a possible tuff ring is also observed at this site.

STOP 13: One mile east of Wallula Gap on U.S. Highway 410. Here, knob-like outcrops of rubbly basalt breccia are seen in conjunction with the purported Wallula Gap Fault. The general relationships of the exposed basalt flows, basalt breccias, and the present erosional surface are discussed.

STOP 14. Columbia River Gorge, seven miles south of Wallula Gap on U. S. Highway 410. At this stop, the Blair Canyon section can be seen on the north side of the gorge (Figure 4, Table 2). Comparable flows of the Frenchman Springs Basalt and Roza members can be studied in the road cut.

RETURN TO Federal Building, Richland, at 5:30 p.m.

FIELD TRIP NO. 7
(Unscheduled)

GEOLOGICAL FIELD TRIP GUIDE

MOUNT ST. HELENS LAVA TUBES, WASHINGTON

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and

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March 1973

MOUNT ST. HELENS LAVA TUBES, WASHINGTON

INTRODUCTION

Abundant volcanic structures seen on high resolution pictures of the Moon and Mars has prompted interest in volcanic landforms as analogs to planetary surface features. Lava tubes have been of particular interest because they appear to be similar to sinuous rilles on the Moon (Greeley, 1971a) and structures associated with shield volcanos on Mars. In 1969 and 1970, the Cave Basalt (Greeley and Hyde, 1972) and associated lava tubes were studied extensively. These tubes are very well preserved and display structures (not generally seen elsewhere) that allow interpretations of lava-tube formation, morphology, and degradation. The lava tubes are on U.S. Forest Service and private lands and, after the spring snows melt, are readily accessible. Part of Ape Cave, a long lava tube segment, has been designated a Geologic Point of Interest by the Forest Service and a parking lot, restroom facilities, and ladders within the lava tube have been provided.

The field trip guide is divided into four sections: 1) road log from Portland to the lava tubes, 2) geological summary of the Mount St. Helens lava tubes, 3) guide to Lower Ape Cave, and 4) guide to Upper Ape Cave.

The highway distance between Portland and the lava tubes is about 96 km (60 miles) (Fig. 1) and requires a driving time of about 1.5 hours. The geology between Portland and the tubes is mentioned briefly to provide a regional geologic setting. The reader is referred to other papers in this guidebook and to publications listed here for more detailed descriptions of local geology. The tour of the Lower Ape Cave requires about one hour; the tour of Upper Ape Cave requires four to five hours.

Part of the original data was gathered during a U.S. Geological Survey investigation of the potential volcanic hazards of the area by Hyde. Greeley made the original study during tenure as a National Academy of Science National Research Council Associate at NASA-Ames Research Center.

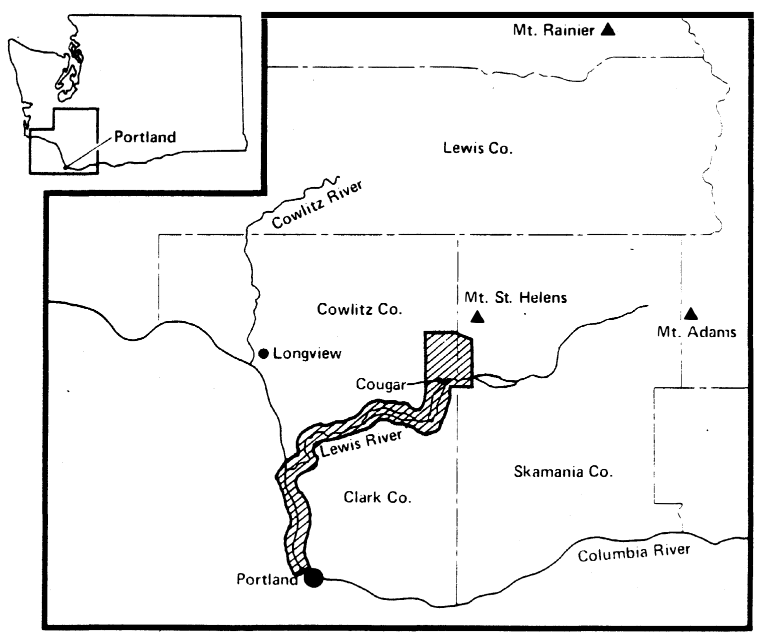

Figure 1. Location map; ruled portion outlines area discussed in guide. Straight-line distance from Portland to lava tubes is about 50 miles.

I. ROAD LOG, PORTLAND TO MOUNT ST. HELENS LAVA TUBES

Mileage (in miles)

Portland is built upon a broad, deltaic Pleistocene fill, formed during catastrophic floods from the Columbia River valley. Subsequently, part of the fill has been terraced and eroded. The deposits consist mostly of sand and gravel in the eastern part with sand, silt, and clay more common to the west and northwest.

0.0 North end Interstate 5 bridge over Columbia River. Follow freeway, which passes
(6.0) from the trench of the Columbia River onto the delta surface.

6.0 Salmon Creek bridge, exposure of Troutdale Formation in gravel pit to west. The formation consists of siltstone, sandstone, and conglomerate more than 1100 feet thick, and is lower Pliocene based on fossil leaves (Trimble, 1957).
(3.0) The abundance of micaceous sandstone and quartzite gravel, not derived locally, suggests that at least part of the sediment was derived from the upper part of the Columbia River drainage.

9.0 Mount St. Helens visible to the north.
(9.0)
18.0 Bridge over East Fork Lewis River; rocks exposed to the east are assigned to the upper Eocene Goble Volcanic Series by Wilkinson, Lowry, and Baldwin (1946). This series
(1.5) consists of volcanic breccia, lava flows, tuffs, mudflows, dikes, sandstones, and conglomerates. The lowest part of the formation is interbedded with marine sandstone.
19.5 Lewis River bridge.
(1.5)
21.0 EXIT. Woodland; exit from freeway, proceed east on Highway 503 to Cougar and Swift Dam.
(3.1)
24.1 To the south a gravel pit exposes sand and pumice that are the downstream equivalent of pyroclastic flows and lahars produced by eruptions of Mount St. Helens. The term lahar is used to designate deposits of debris that result from rapid mass flowage of water-mobilized material down the flanks of a volcano. It is also used to designate the flow-
(4.5) ing mass.

Small landslides are common in the deeply weathered older glacial drift exposed in road cuts for the next few miles.

28.6 Road to Salmon Hatchery, note large landslide.
(1.0)
29.6 Crossing Lewis River terraces; note terraces across river.
(0.6)
30.2 Small landslide to the north.
(0.3)
30.5 Road cuts in volcanic breccias and lava flows assigned to the Goble Volcanic Series by Wilkinson, Lowry, and Baldwin (1946).
(0.8)
31.3 Road to Merwin Dam.
(0.7)
32.0 Road cuts in lava flows capped with fluvial gravel. Road cuts for the next several
(3.9) miles expose interbedded sandstones and shales.
35.9 Bridge.
(1.7)
37.6 Merwin Reservoir below.
(1.0)
38.6 Bridge.

Figure 2. Oblique aerial overview of the Cave Basalt; Mount St. Helens in background; main entrance to Ape Cave in middle distance; spillway of Swift Reservoir and road N90 in foreground. Photo courtesy U.S. Forest Service

Mileage

(0.7)

39.3 Tumtum Mountain (visible ahead) is a cinder cone older than the last glaciation. (Fraser Glaciation)

(1.6)

40.9 Descending to the Lewis River valley; ahead is the relatively flat surface of lahar and fluvial deposits which represent the older episodes of explosive volcanism of Mount St. Helens.

(0.9) Road cuts to the north show interbedded sedimentary rocks and lava flows which may be part of the Ohanapecosh Formation.

41.8 Road to Speelyai Bay boat launch and picnic area.

(2.3)

44.1 Road to Yale Dam, Yacolt, and Amboy.

(0.3)

44.4 Summit of Mount St. Helens visible ahead.

(0.9)

45.3 Speelyai Creek Bridge.

(2.1)

47.4 Boat launching and picnic area to south. Sedimentary and volcaniclastic rocks exposed in road cuts are assigned to the Ohanapecosh Formation by Hopson (1971, personal

(1.2) commun.).

48.6 Road to Merrill Lake; good exposures of the Ohanapecosh Formation cut by a sill occur

(0.2) in road cuts between here and Merrill Lake (Hyde, 1970).

48.8 Lahars younger than those in the Speelyai Bay fill are exposed in the Highway Depart-

(0.5) ment gravel pit to the right. A weathered zone as thick as 8 cm (3 in.) separates the two youngest lahars.

49.3 Cougar Store; between here and Swift Dam as many as 8 terrace levels are present and

(2.2) record a complex sequence of valley filling and erosion.

51.5 Road to Beaver Bay campground. The terraces here conceal the western margin of the

(0.9) Cave Basalt flow (Fig. 2,3).

The Cave Basalt (Greeley and Hyde, 1972) is a high-alumina pahoehoe flow which originated at the southwest flank of Mount St. Helens and flowed south about 11 km (6.5 miles) down a stream valley cut into late Quaternary lahar and pyroclastic flow deposits. The upper part of the basalt is covered with younger lava and surficial deposits, but it is present at least as high as the 1,465 m (4,800 feet) elevation on the volcano. The flow terminates on the north bank of the Lewis River.

The basalt rests on river gravels exposed at the east end of the private logging road bridge across the Lewis River south of the main highway. The basalt-flow surface ranges from flat to hummocky over broad areas and is commonly broken into large tilted slabs. Common surface features include ropy or corded textures, pressure ridges, and tumuli that are often cracked or collapsed. The term tumulus is used here for any dome-shaped, circular or semicircular, solid or hollow surface feature. Many of the known hollow tumuli of the Cave Basalt are collapsed, leaving raised-rim craters up to 50 m (164 feet) in diameter. The age of the basalt flow is probably close to 1,900 years B.P. Charcoal from roots exposed in breakdown areas in both Lake and Ape Cave were dated by radiocarbon methods and are 1,900 years old.

Surface features of the lava flow are well-displayed between here and the margin of the basalt near the east entrance to the private logging road.

52.4 West entrance to private logging road.

(0.1)

52.5 East entrance to private logging road, well-developed pressure ridge to north (Fig.4).

(0.8)

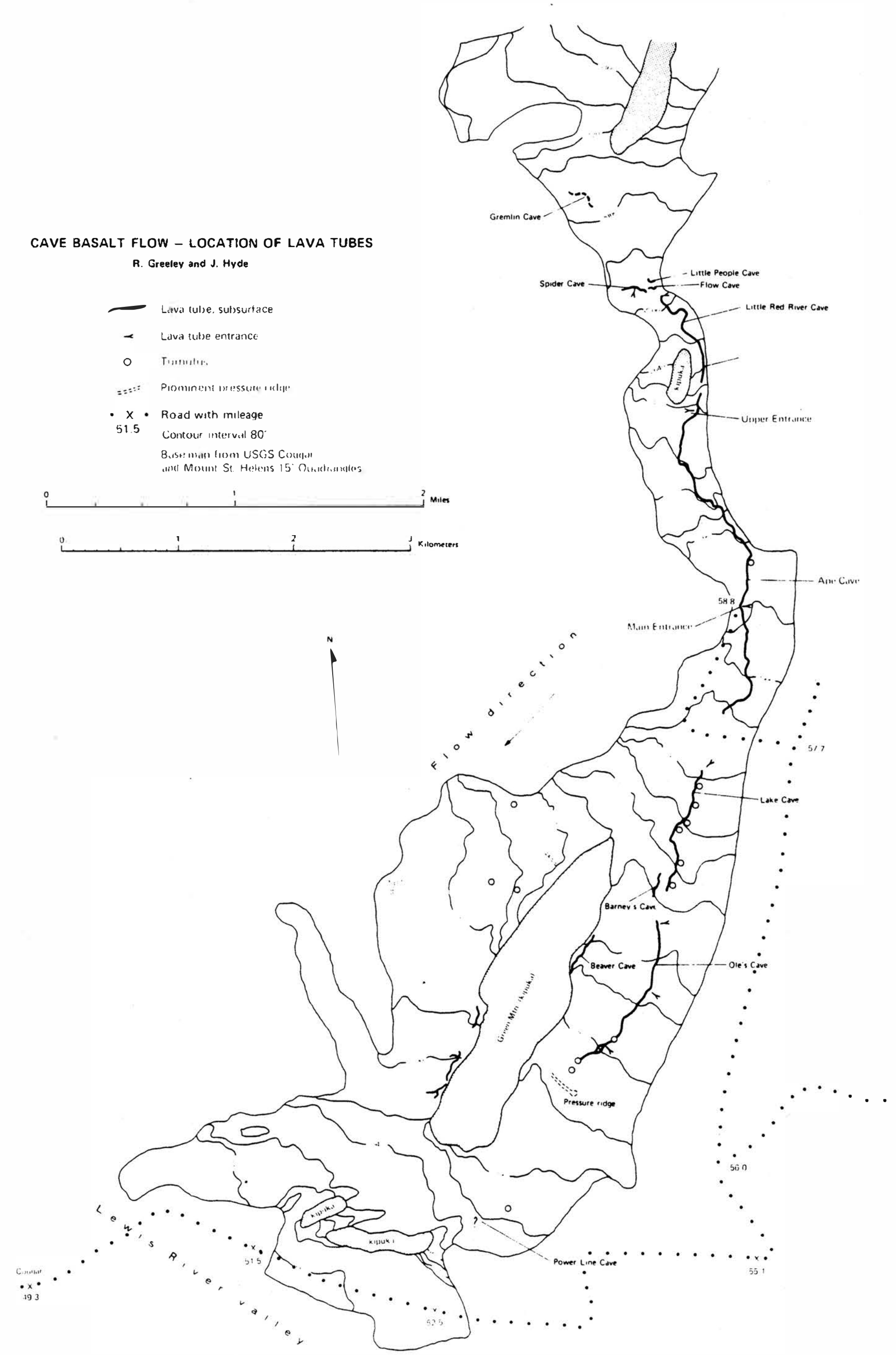

Figure 3. Map showing location of lava tubes and road to Ape Cave.

Figure 4. Pressure ridge with medial crack, mile 52.5.

Mileage

53.3 Bridge across power canal. The oldest dated volcanic deposit at Mount St. Helens is a wood-bearing lahar (36,000 years old) exposed at river level. Road cuts between here
(1.8) and dam viewpoint exposed portions of the valley fill which consists of fluvial sand and gravel, lahars, and (near the viewpoint) pyroclastic flow deposits.

55.1 Dam viewpoint. The viewpoint is located near the top of a thick sequence of volcanic debris which forms a large fan across the Lewis River at the mouth of Swift Creek. Pumice-flow deposits form the upper units in the fan.
(0.3) In the gravel pit on the south side of the Lewis River valley the pumice flow contains charcoal which has been dated at about 20,000 years B.P.

55.4 Mount St. Helens viewpoint. Volcanic ash erupted as recently as 1842. In the last few hundred years there has been frequent violent volcanism accompanied by hot pyroclastic flows, lahars, pumice eruptions, and lava flows. The dark, fresh-looking lava
(0.6) flows visible from this point are mainly younger than 450 years. Geologic studies on the volcano are listed at the end of the guide.

56.0 EXIT. Turn north on gravel road N83. The white pumice at the surface is Layer W,
(1.7) erupted about 450 years ago. It is about 5 to 10 cm (2 to 4 in.) thick here, but in the vicinity of Spirit Lake on the north side of the volcano it is 30 to 100 cm (1 to 3 feet) thick. Older pumice layers are visible below Layer W.

57.7 Turn west on road N816.
(0.2)

57.9 Lava Cast area. Vertical and horizontal tree molds are particularly well displayed here. The trail from the parking lot leads to the entrance of Lake Cave, part of the Mount
(0.4) St. Helens lava-tube system.

58.3 Road cut is in a pyroclastic flow deposit similar to those exposed in collapsed wall sections in the lava tubes.
(0.5)

58.8 Main Entrance, Ape Cave lava tube.

II. MOUNT ST. HELENS LAVA TUBES

General description

The Cave Basalt contains sections of lava tubes extending nearly the entire length of the flow. The principal lava tube system in the flow is composed of Little Red River Cave, Ape Cave, Lake Cave, and Ole's Cave (Table 1).

Table 1. Physical characteristics of lava tubes in the Cave Basalt

Name	Length* (m)	Maximum Height (m)	Maximum Width (m)	Average Slope
Ape Cave	3,400	11.6	12.2	3.3°, 1 m/17.2 m
Barney's Cave	56	2.7	3.6	2.0°, 1 m/27.8 m
Bat Cave	330	3.7	16.2	-- --
Beaver Cave	477	9.1	15.2	3.0°, 1 m/19.6 m
Dollar-Dime Cave	---	----	----	-- --
Flow Cave	99	2.4	4.6	3.2°, 1 m/17.4 m
Gremlin Cave	---	----	----	-- --
Lake Cave	1,248	15.5	9.1	2.6°, 1 m/22.2 m
Little People Cave	143	4.6	7.9	1.3°, 1 m/47.7 m
Little Red River Cave	1,032	9.1	11.9	4.5°, 1 m/11.7 m
Ole's Cave	1,592	7.6	13.1	2.1°, 1 m/27.4 m
Powerline Cave	---	----	----	-- --
Prince Albert Cave	480	6.1	15.0	-- --
Spider Cave	271	4.6	11.4	-- --

* For lava tubes with multiple passages, length represents main passage only.

Although the system begins in the constricted northern part of the flow, it probably originated upslope, above Little Red River Cave. The system trends southward along the east flow margin and apparently terminates in collapsed tumuli east of Green Mountain kipuka*. Ape Cave, with a passage length of 3,400 m (11,330 feet), is one of the longest uncollapsed lava-tube segment known.

Lava-tube formation is apparently controlled primarily by lava flow viscosity, which in turn is related to the chemistry, dissolved gasses, temperature, and flow velocity of the lava. At least two modes of tube formation are displayed in the Cave Basalt, and both may occur within a single tube in different localities. Most of the tubes apparently formed between shear planes that developed within laminar flow of the molten lava (Fig. 5), similar to the mode of formation described by Ollier and Brown (1965). Where the flow gradient increased, however, the active flow probably became turbulent, destroying the laminar flow and shear planes, and the tube roof probably formed by accretion of spattered lava on lateral levees as observed in active lava flows (Greeley, 1971b, 1972).

Lava flows and tubes are controlled to some degree by pre-flow topography and are usually situated in topographic depressions. Lava tubes represent the zone of highest flow velocity within the overall flow body, analogous to a hydrologic thalweg; as such, the axis of the developing tube may migrate in a sinuous pattern within active flows. Some sections of the Cave Basalt tubes, however, appear to occupy the bed of a former stream, indicated by exposures of country rock where sides of the tube have collapsed. These exposures also reveal that lava flows are capable of eroding pre-flow surfaces, shown by undercut sections of country rock and country rock inclusions in the basalt (Fig. 6).

* Island of older rock surrounded by younger lava.

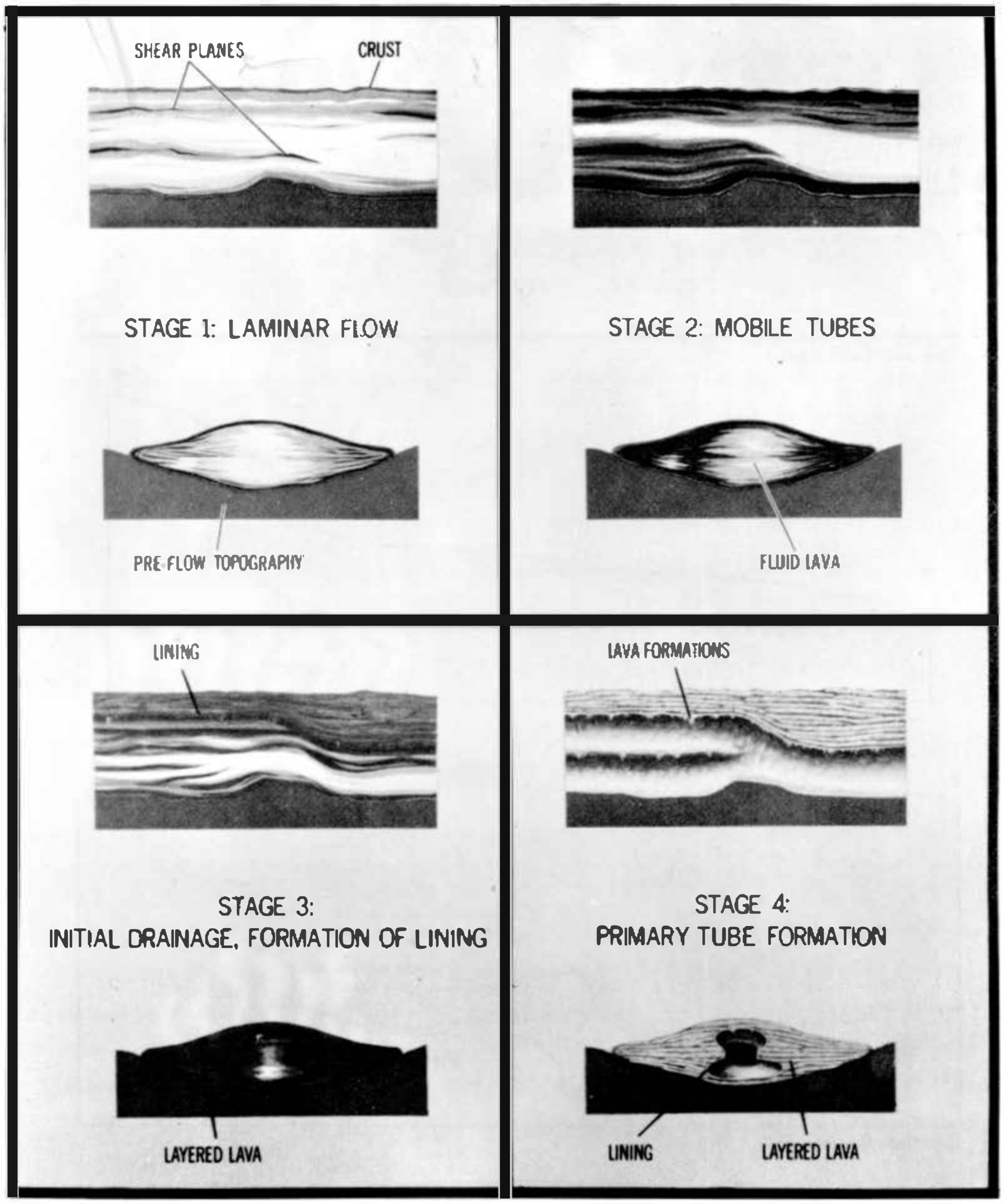

Figure 5. Diagrams illustrating lava-tube formation associated with shear planes developed in laminar lava flow. Each stage is shown in longitudinal profile (parallel to flow axis, top diagram) and in transverse cross section (normal to axis, lower diagram). The tube cross section in stage 4 is shown with an hourglass outline to emphasize that noncircular tubes may form within a single flow (after Greeley and Hyde, 1972).

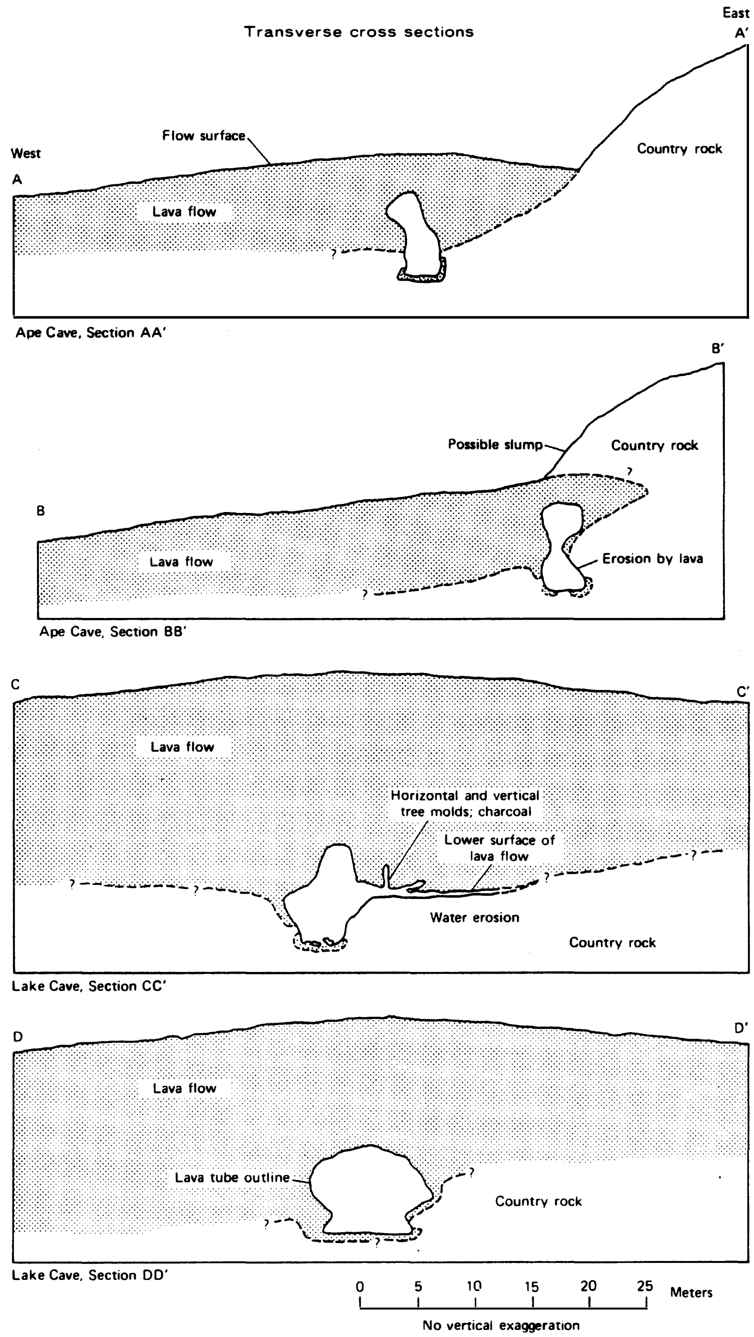

Figure 6. Transverse cross sections, Mount St. Helens lava-tube system, showing relations of lava tube to lava flow and preflow country rock. In these sections, the lava tube is interpreted to occupy a former stream channel (after Greeley and Hyde, 1972).

Ape Cave

Ape Cave was named for a group of local cave explorers who called themselves the St. Helens Apes, after large, hairy, ape-like creatures which were reported in the early 1920's to have attacked a group of miners working on the east side of the volcano.

The tour of Ape Cave is divided into two parts; the segment of the tube downslope (south) from the main entrance is 1,330 m (3,910 feet) long and requires about 1 hour for a round trip. This segment is easily travelled, but there is no lower exit and the return is made back through the tube. The portion of the tube upslope (north) from the main entrance is more interesting geologically, but a few areas of breakdown (collapse-block from the ceiling) are present, necessitating short crawls. An exit is present at the end of the upper segment and the surface of the lava flow can be followed for a return to the parking lot at the main entrance. The upper segment is 2,470 m (7,420 feet) long and requires a roundtrip of 4 to 5 hours.

For safety and enjoyment we recommend that you have a lantern in addition to a flashlight, warm clothes, boots, hard hat, and gloves. The upper segment of the lava tube should not be travelled alone. Standard caving practice calls for three independent light sources (e.g. lantern, flashlight, candle with matches).

Distances to localities within the tube are necessarily approximate and are given in paces (one pace equals five feet, or two steps). The tube walls are referred to as either the east wall or west wall (the tube is assumed to run north-south with upslope to the north).

Tube entrance

The entrance to the tube is a collapsed tumulus which once formed a chamber above the main lava tube. Layered lava is visible in the walls of the entrance.

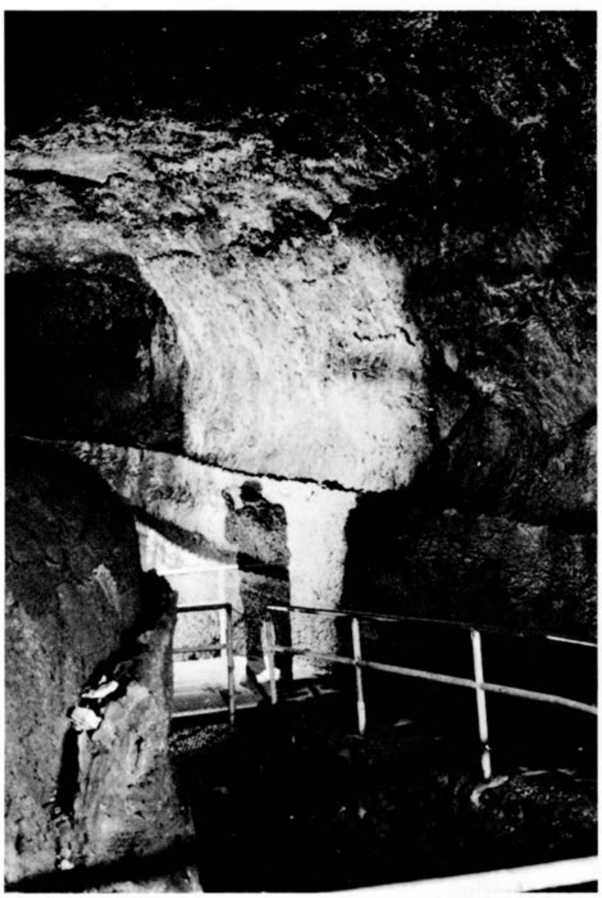

Figure 7. Lava-tube interior near top of stairway, main entrance to Ape Cave, showing lava flow gutters. View downtube. Photo courtesy F. Dippolito

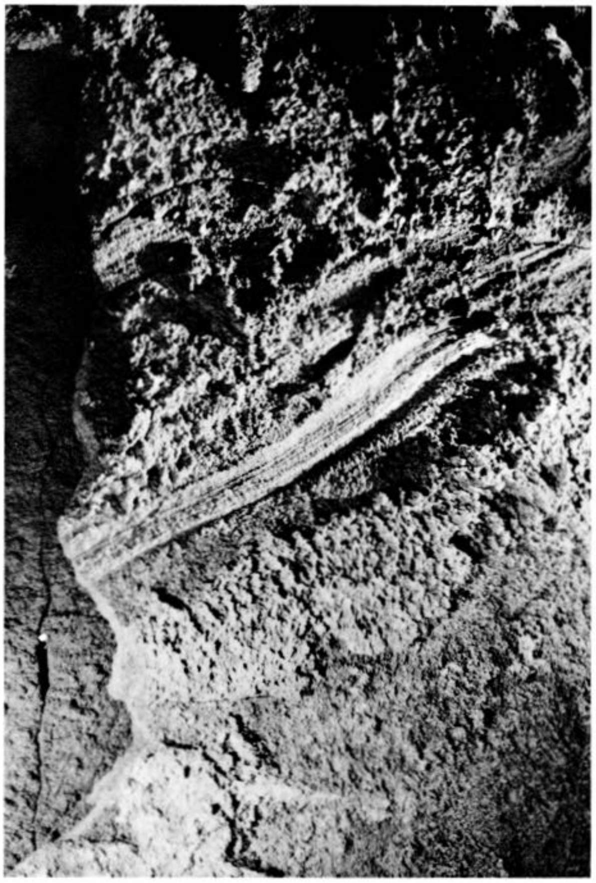

Figure 8. Drag mark on west wall, near main entrance to Ape Cave, caused by a block carried by the lava stream and coming in contact with the still plastic tube lining. Mark about 1 m (3 feet) long.

Figure 9. Lava-tube interior near main entrance, Ape Cave, showing complex cross section, multiple "flow" lines, and meandering nature of lava tubes. Tube is about 13 m (40 feet) high.

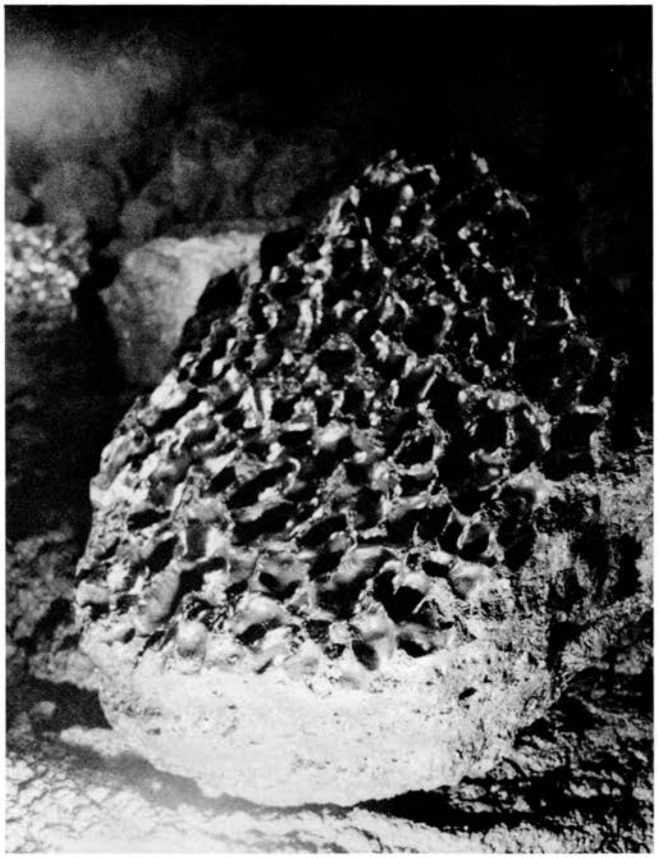

Figure 11. A fallen roof block similor to those at pace 0 (and elsewhere) showing development of a glassy surface. Block about 1 m (3 feet) in maximum dimension. Photo courtesy F. Dippolito

Figure 12. Wall section of lower Ape Cave at pace 44, showing where wall collapsed, allowing the country rock (a pyroclastic flow deposit) to slump into the tube. Molten lava which dripped on the material, and the fusion of the slumped sediment to the tube lining, shows that collapse occurred before the lava flow had completely cooled. Pack gives scale. Photo courtesy F. Dippolito

Top of lower stairway

Lines and ledges caused by partial cooling of the surface during temporary halts in the lava flow are visible on the sides of the tube (Fig. 7). Remnants of later lava flows that moved through the tube are present on the tube floor. The drag mark (Fig. 8) on the west wall was caused by a block being carried on the surface of the lava stream and coming in contact with the still plastic tube lining. The tube here (Fig. 9) is about 13 m (40 feet) high and appears to have been modified by subsequent flow alteration. Apparently two or more lava surges flowed both through an existing tube and over the surface of the tube. These later flows apparently remelted the existing roof to extend the tube vertically, forming a vertically elongate cross section. An alternative explanation for multiple-level tubes and vertically elongate cross sections is that individual conduits of lava developed within a single massive flow. As cooling progressed, the conduits may have merged to form single, elongate tubes, or may have developed as individual tubes stacked vertically. In come areas, the conduits merged and separated alternately along the course.

Bottom of lower stairway

The sand and pumice on the tube floor have been carried in from the outside by streams and, in some areas, completely plug the tube. Where the sand surface is undisturbed, patterns have been sculptured by water dripping from the roof.

The luminescence of the walls is due to light reflecting from water droplets and "cave slime."

In the later stages of tube formation, probably during drainage, a layer of lava is accreted along the walls and ceiling to form a lining. Lava-tube linings range from less than 1 cm to more than 1 m thick and are generally somewhat more vesicular than the main body of the lava flow. Vesicularity within the lining may increase toward the tube, possibly representing outgassing into the tube. During or after drainage, parts of the lining may develop a glassy surface. Glaze that is deformed must have developed while the lining was still plastic and subject to movement. Formation of glaze is not well understood; however, it appears to develop as a thin coating over the outer vesicular zone of the lining, possibly as a result of rapid cooling by air currents in the lava tube.

Longitudinal profiles of Mount St. Helens lava tubes (Figure 10) in pocket.

III. LOWER SEGMENT TOUR - APE CAVE

Paces (5 feet)	
0	Bottom of lower stairway, main entrance (Fig. 10). Proceed downtube (south). The blocks lying on the floor have spalled from the roof of the tube (a continuing process).
(44)	Note the development of a glassy surface (Fig. 11).
44	Here the west wall of the tube collapsed, allowing the country rock (a pyroclastic flow deposit) to slump into the tube (Fig. 12). Molten lava which dripped on the country rock and then cooled and fusion of the slumped material to the tube lining show that collapse occurred during or immediately following drainage of lava from the tube. The country rock is baked a brilliant red.
(6)	
50	Step down, watch head: fallen roof block.
(28)	
78	Note the presence of a small subsequent lava flow. Many good examples are present in this tube segment of deformation of the visco-elastic semimolten lava-tube lining, which produces wall drapery.
(90)	
168	Discontinuous exposures on both walls of brick-red lava clinkers (autobrecciated lava) between the lining and the massive basalt of the flow. Differential movement of the lining and massive basalt may produce a shear zone along which the autobrecciated lava forms. Brecciation may also have occurred by vesiculation into possible voids and low-pressure areas between the lining and the body of the flow, similar to the process described by Parsons (1969) for lava flows in general.
(142)	

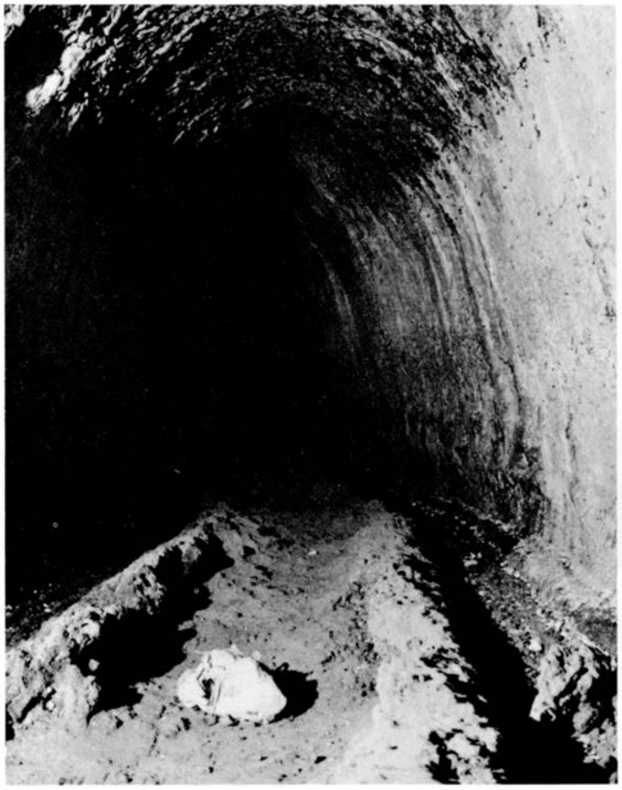

Figure 13. Lava levees developed on small subsequent lava flow at pace 425, lower Ape Cave. View uptube, pack gives scale. Photo courtesy F. Dippolito

Figure 14. Block rafted to its present position by a small floor flow and fused to tube lining, pace 450, lower Ape Cave. Tripod gives scale.

Figure 15. Balls of lava wedged between and fused to the tube walls during drainage of molten lava from the tube. Note well-developed wall drapery. View uptube at pace 468, lower Ape Cave.

Figure 16. Tube interior at pace 481, lower Ape Cave, showing a ball of lava similar to those at pace 468. Note the flow lines near the base of the walls and the scattered white pumice fragments on the floor.

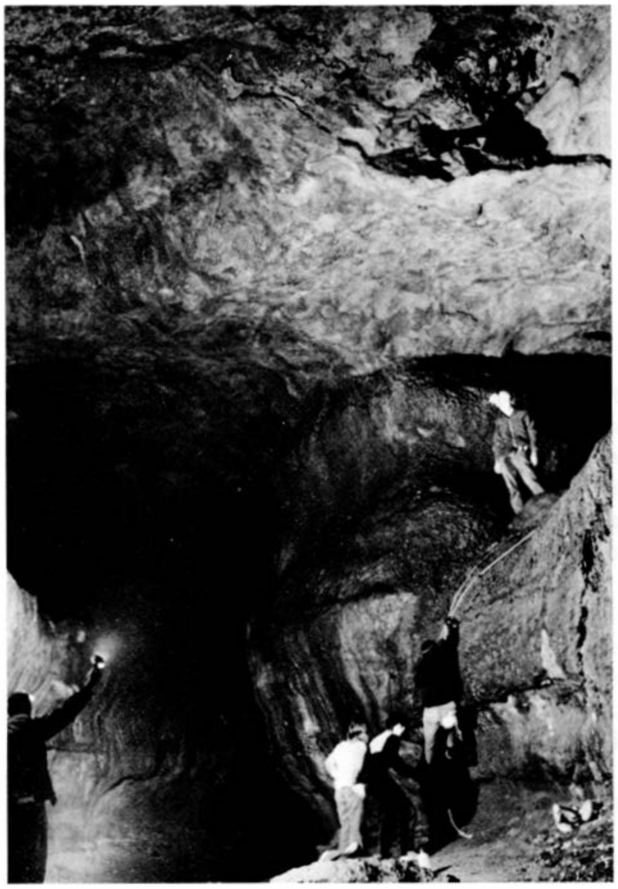

Figure 17. Tube interior at pace 690, lower Ape Cave, showing development of a short upper passage. View uptube. Photo courtesy P. Clee

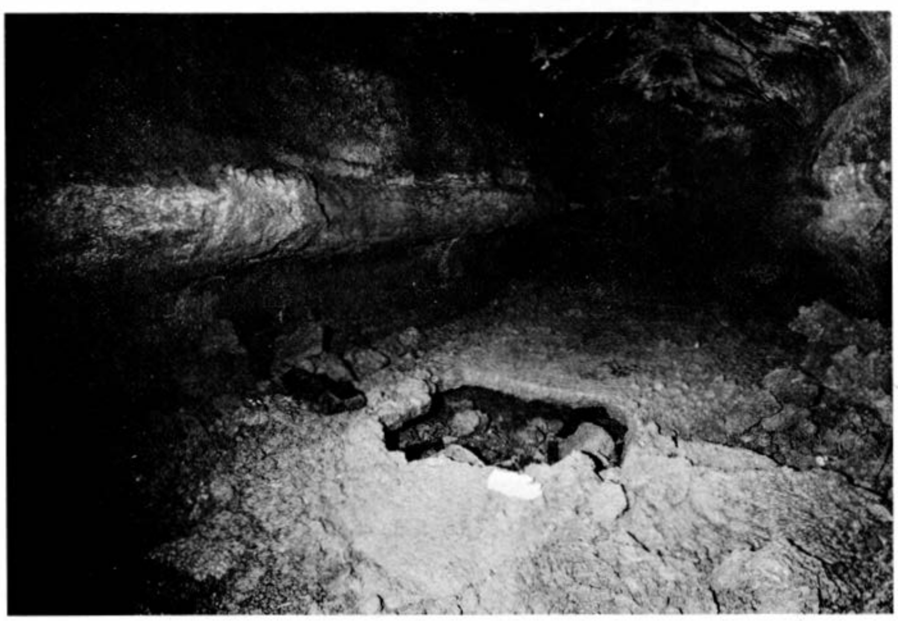

Figure 18. A small lava tube developed in a subsequent floor flow resulting in a tube-in-tube structure. View uptube about 10 paces north of main entrance, Ape Cave.

Paces (5 feet)	
310	A cupola (a bulbous chamber in the ceiling) is present at this point; its surface expression is a dome 20 m (60 feet) in diameter. The roof is about 5 m (15 feet) thick here.
(30)	The cupola probably formed by hydrostatic pressure within the closed tube systems and outgassing into the tube interior. In some places, pressure apparently was great enough to rupture the roof.
340	Well-formed wall drapery.
(40)	
380	Floor steepens.
(45)	
425	Well-developed lava levees on small floor flow (Fig. 13).
(25)	
450	Tube narrows; note the block near the base of the east wall (Fig. 14). The block is fused to the tube lining and, since at this point there is no obvious source for it on the roof, it must have been rafted to its present position by a subsequent floor
(18)	flow or during final drainage of the tube.
468	Tube narrows, note several balls of lava wedged between and fused to the tube walls
(13)	during drainage of molten material from tube (Fig. 15).
481	Single ball of lava wedged and fused to walls (Fig. 16).
(25)	
506	Start of discontinuous exposures of red lava clinkers in west wall caused by collapse of
(94)	tube lining. Exposures continue downtube for about 85 m (255 feet).
600	The sand and pumice fill becomes thicker here and a well-developed terrace is present, presumably caused by the reduced velocity of the stream as it encountered the wider
(52)	cross-section of the lava tube.
652	Cupola; the tube is about 12 m (35 feet) high here. The roof is 3 to 5 m (9 to 15 feet)
(38)	thick.
690	A short upper level is present (Fig. 17); note the well-developed lava stalactites. The
(72)	section between this point and the end of the tube contains a sand and pumice fill which in some places is more than 1 m (3 feet)thick.
762	End of tour. The upper level is passable for a short distance; the roof of the lower level meets the sand fill and the tube becomes impassable about 30 m (100 feet) farther.
(20)	A small cave with a slight breeze at the entrance is located on the surface at about this point, which is 300 m (900 feet) north of the Forest Service road at the Lava Cast area.
782	End of tube; retrace route to EXIT.

IV. UPPER SEGMENT TOUR - APE CAVE

Paces (5 feet)	
0	Bottom of lower stairway, main entrance. Proceed uptube (north). Well-developed levees and gutters, formed by subsequent lava flows, are located 5 to 15 paces uptube. A floor flow displays a small lava tube, resulting in a tube-in-tube structure (Fig. 18).
(96)	Note that the surface of the flow is broken into plates which were rafted from uptube. The blocks that have spalled from the ceiling show development of a glassy surface.
96	Large breakdown area; the roof is about 7 m (21 feet) thick here. Lava-tube collapse after cooling begins with spalling of the tube lining. This is followed by spalling and collapse of basalt blocks from the roof, eventually forming a small opening (termed a skylight) to the surface. Some parts of lava tubes are marked by extensive collapse,
(36)	as here, (not necessarily breaking through to the surface, however) that may completely

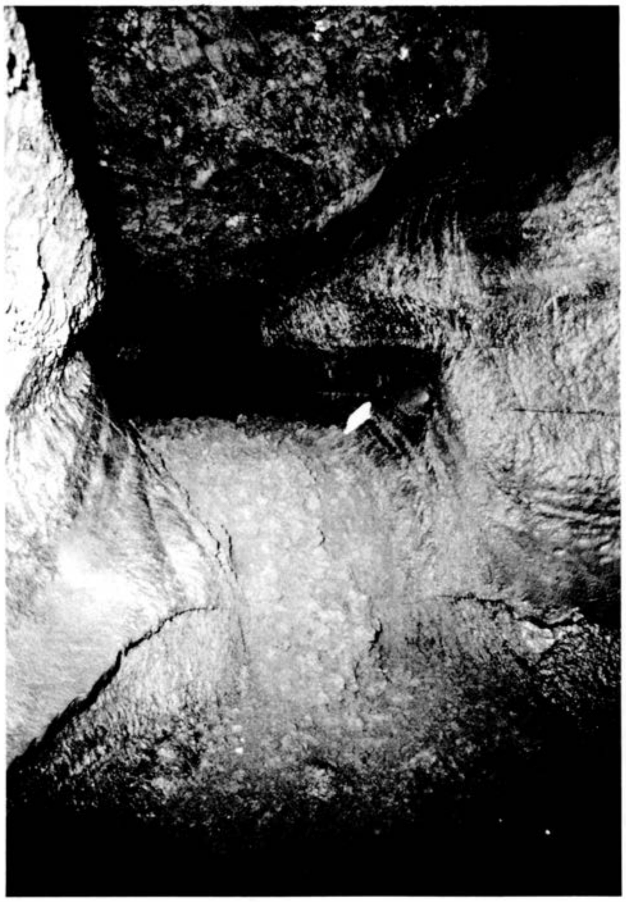

Figure 19. Interior of lava tube at pace 522, upper Ape Cave, showing a floor flow which poured over an abrupt rise in the tube floor. Notebook gives scale; view uptube.

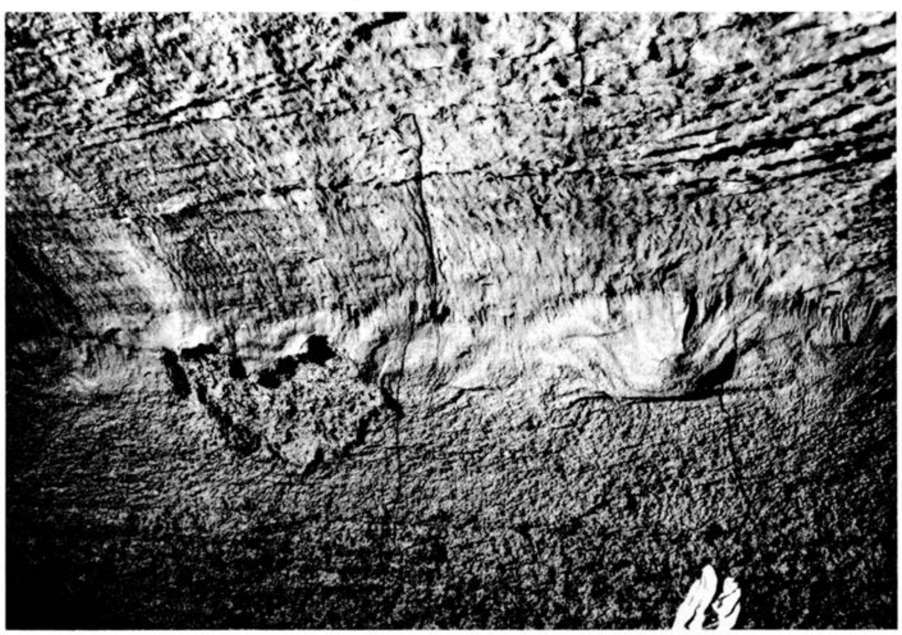

Figure 20. Tube wall near pace 526, upper Ape Cave, showing ruptured blister and a possible nonruptured blister probably caused by gas collecting behind the semimolten tube lining. Note wall drapery and "flow" lines; glove gives scale.

Figure 21. The terminus of a small subsequent oo lava flow similar to those at pace 668 and 801, upper Ape Cove. View uptube; width of tube about 2 m (6 feet).

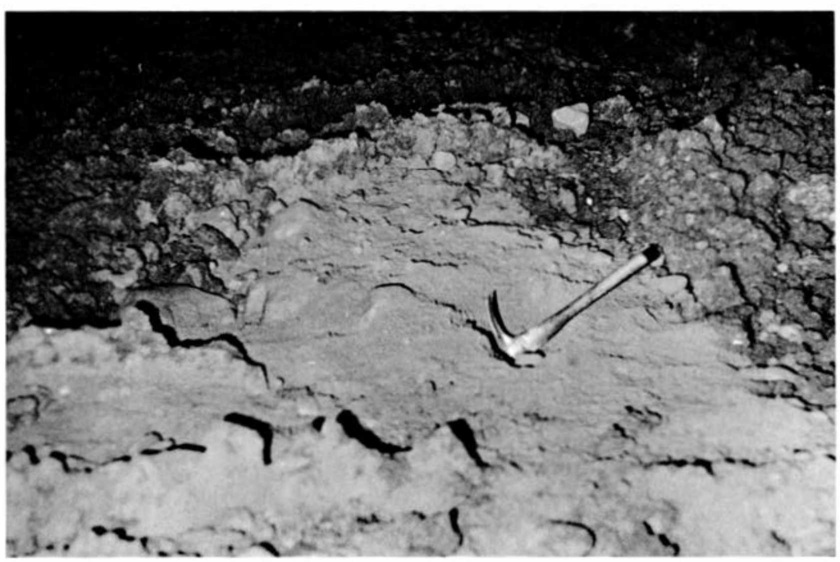

Figure 22. Lava tube floor showing probably exposure of country rock, pace 731, upper Ape Cove. Pick handle about 45 cm (18 inches) long.

Paces (5 feet) block the interior passage. The small tube on the west side of the chamber is about
25 m (75 feet) long. Note the development of the wide shelves on both sides of the
main tube. The best path over the breakdown area follows the east wall.

132 Large roof breakdown area. Several smaller intermittent sections of roof breakdown
(118) occur in the next 197 m (590 feet).

250 End of roof breakdown area. The floor flow here is aa lava.

(272)

522 Tube narrows and floor rises 1.7 m (5 feet) (Fig. 19). Lava stalactites are well devel-
oped here. A series of ruptured blisters occur on the west wall of the tube, probably
caused by gas collecting behind the semimolten tube lining.

(94) A possible nonruptured blister is present on the west wall about 7 m (21 feet) uptube
(Fig. 20).

616 Rise in floor.

(52)

668 Terminus of small floor flow (Fig. 21).

(10)

678 An area of wall breakdown about 35 m (105 feet) long has exposed the valley wall at
this point. The country rock (a pyroclastic flow deposit) is baked a brilliant red and
(53) contains fragments of charcoal which were radiocarbon dated at 1,900 years B.P.

731 Country rocks (?) exposed in floor (Fig. 22).

(19)

750 Wall breakdown area, exposing country rock. On the west wall directly opposite the
breakdown area, silt- to sand-sized particles of the country rock are fused to the tube
(40) lining, showing that the wall rupture was explosive. The explosion was probably
caused by interaction of molten lava with stream water, snow, or ground water (Hyde
and Greeley, 1971), although generation of hydrocarbon gasses by destructive distil-
lation of vegetation buried by lava flow is known. The particles are fused to the down-
tube side of protuberances on the tube lining for at least 500 m (1,500 feet) uptube.
A block of dacite which has melted and flowed downward is visible on the west wall
at the uptube (north) end of the breakdown area.

790 Breakdown area; country rock exposed in both walls. Near the northern end of the
breakdown area, on the east wall, blocks of dacite contained in the pyroclastic flow
deposits have melted and flowed out through breaks in the lava-tube lining. The melted
(5) material is light tan and in one example formed a molten stream 20 cm (8 inches) wide
and 1 m (3 feet) long (Fig. 23).

795 Rise in floor of 2 m (6 feet).

(6)

801 Terminus of floor flow, note particles of country rock fused to the flow.

(54)

855 Note the exposure of country rock in the east wall at the uptube end of the breakdown
area. Here the country rock is overhanging the lava tube. It is unlikely that this was
the original configuration of the topography in an area of easily eroded unconsolidated
deposits; this and other overhangs in the tube probably represent erosion by the lava
flow. Sections of Little Red River Cave, for example, undercut parts of the eastern,
preflow hillside. Thus, to some degree the position of the tube is determined by the
erosive capability of the lava flow.

Wall breakdown areas and exposures of country rock deposits (rare in most other
areas) provide a unique opportunity to study relations of lava tubes and flows to pre-
flow topography. From exposures available in Ape Cave and in other parts of the tube
system, we conclude that parts of the lava tube are situated in a prelava-flow stream
(23) channel. This channel is about as deep and wide as the present stream channel of
Panamake Creek, a small stream a few miles west of the Cave Basalt but unaffected by
Holocene volcanic eruptions.

Sections (Fig. 24) of the tube along the presumed stream channel assume a skull-

Figure 23. Tube wall showing flowage of melted dacite block down tube wall at pace 790, upper Ape Cove. Glove gives scale. Photo courtesy P. Clee

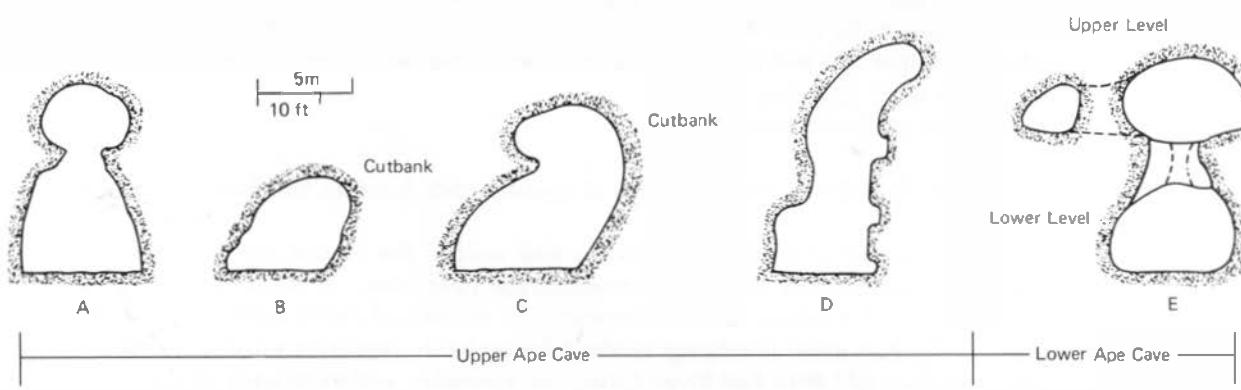

Figure 24. Transverse cross sections of Ape Cove lava tube showing "cutback" configurations and multiple-level development. Stippled area represents lava containing the tube: A. lower Ape Cove near main entrance (about pace 50); view uptube; B. upper Ape Cove (about pace 300); view uptube; C. upper Ape Cove (about pace 400); view uptube; D. upper Ape Cove (about pace 225); view uptube; E. lower Ape Cove (about pace 445); view uptube.

shaped cross section; undercutting by the flow may form asymmetric sections. Some sections in the middle of the flow on gentle gradients have horizontally oval sections which may be due, in part, to lateral erosion. Tube configurations in meander bends are often asymmetric, forming cutbanks similar to stream beds. Further evidence of erosion by lava is found in the form of inclusions of country rock in the lava flow.

Paces	
878	The tube lining has ruptured near the base of the wall and molten lava behind the lining, and (at some points) melted dacite blocks have spilled over the lining and into the tube interior.
(7)	
885	Breakdown area.
(11)	
896	Short upper tube present.
(24)	
920	Small rise in floor; large breakdown blocks fused to floor and walls. Note the fused particles of country rock (result of phreatic explosion).
(27)	
947	Breakdown area, exposures of country rock. A ball of lava is wedged between and fused to the tube walls near the uptube end of the breakdown area.
(80)	
1027	Breakdown area, many exposures of country rock and melted dacite blocks.
(21)	
1048	Breakdown area; it is possible to crawl for about 8 m (24 feet) along the contact between the lava flow and the country rock.
(69)	
1117	Small breakdown area.
(35)	
1152	Skylight and short upper tube. A floor flow with well-formed levees, ropy texture, and slabs is present in the section uptube from the skylight. In this section and uptube from the next small breakdown area, the tube lining has ruptured near the base of the east wall and molten lava has spilled into the tube.
(74)	
1226	Area of small breakdown, lava clinkers exposed in west wall in segment uptube.
(54)	
1280	Large breakdown area, the roof is about 10 m (30 feet) high here.
(24)	
1304	Rise in floor. The segment between this point and the skylight shows well-developed side shelves and ruptured wall lining.
(76)	
1380	Skylight.
(10)	
1390	Skylight, EXIT. The Ape Cave lava tube segment terminates about 157 m (470 feet) beyond (north of) the skylight.
(94)	
1484	End of tube: the terminus of the next lava tube segment (Little Red River Cave) is about 60 m (180 feet) upslope (north).

The east side of the lava flow surface offers the best return path. Many surface features of lava flows are well displayed along the return path. A large crater is present at the point where the path intersects a logging road near the parking lot.

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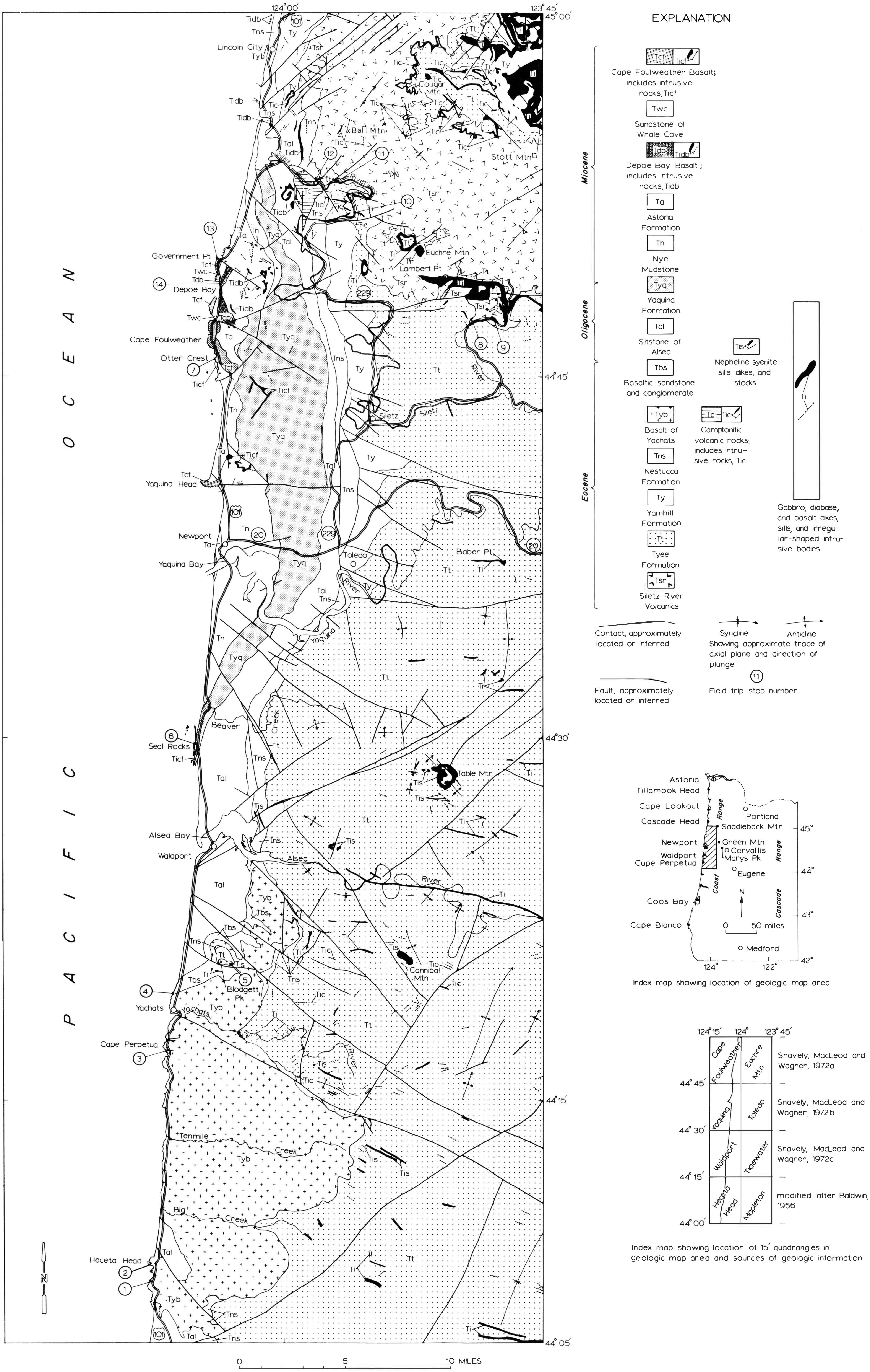

Plate 1. Bedrock geologic map of the west central part of the Oregon Coast Range

NEHALEM BASIN SUBSURFACE SECTION

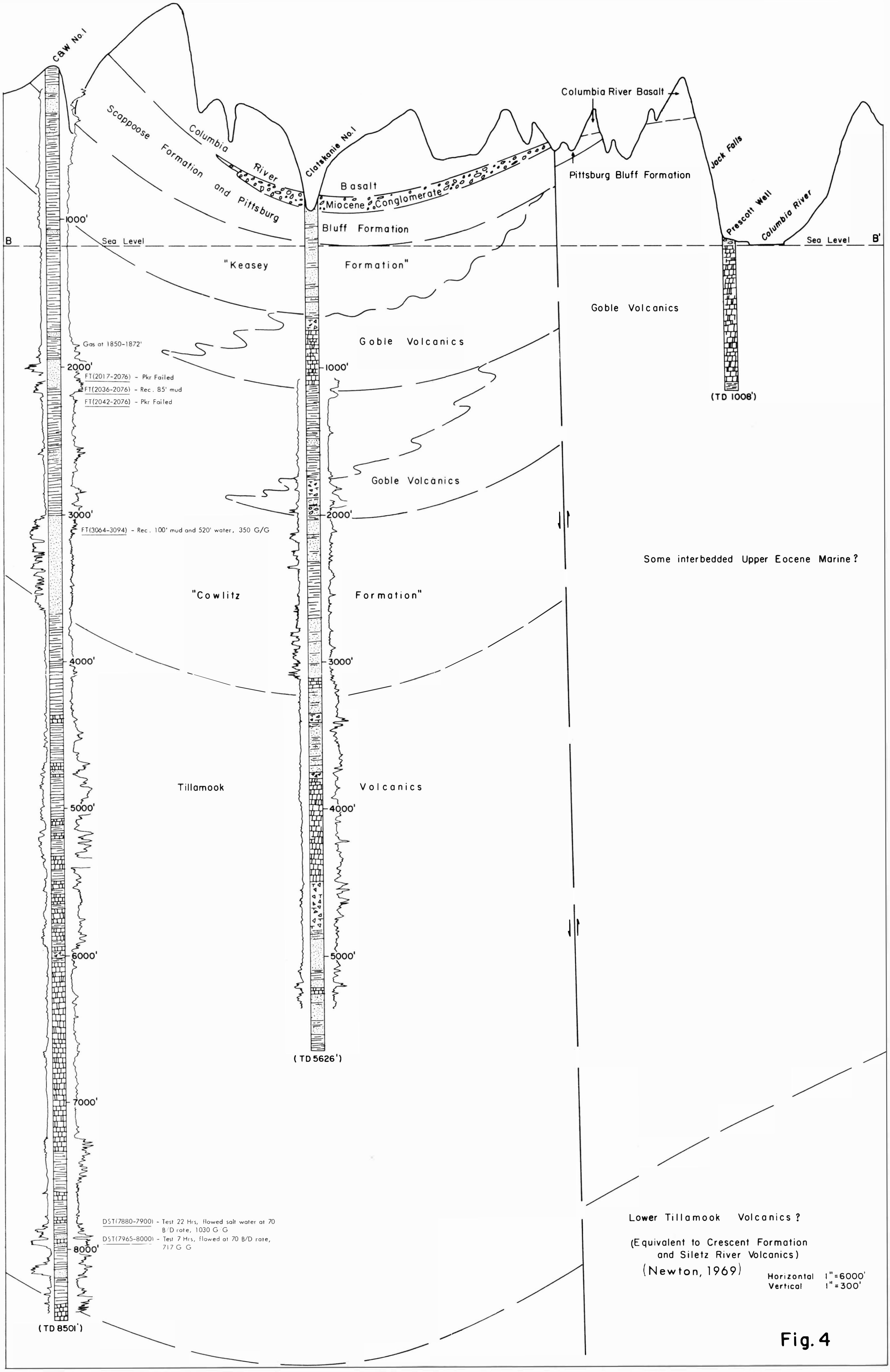

Fig. 4

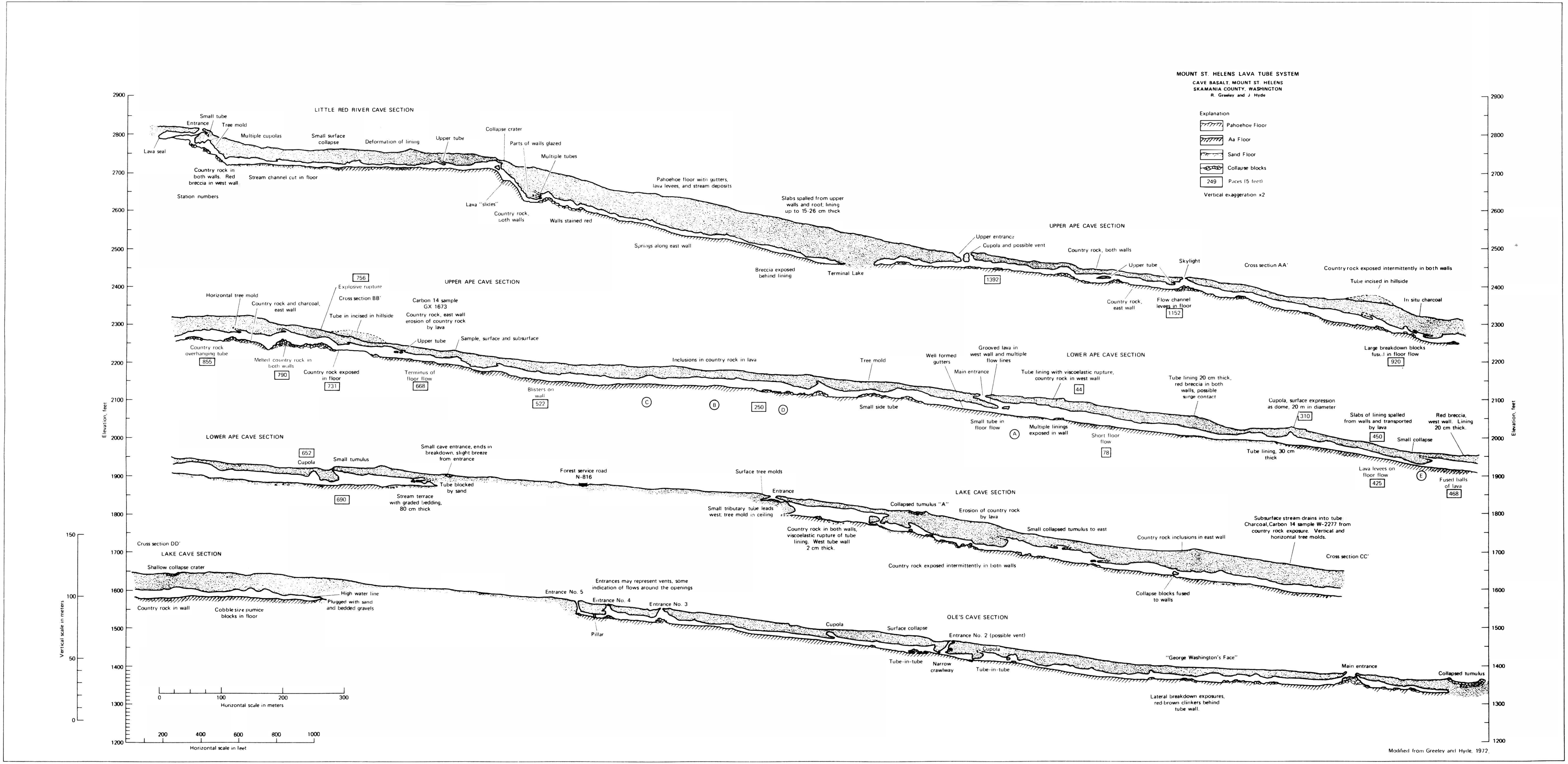

Figure 10. Longitudinal profiles of Mount St. Helens lava tubes.