Sedimentary and Igneous Rocks of the Grays River Quadrangle, Washington

GEOLOGICAL SURVEY BULLETIN 1335

Prepared in cooperation with the State of Washington

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By EDWARD W. WOLFE *and* EDWIN H. McKEE

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SEDIMENTARY AND IGNEOUS ROCKS OF THE GRAYS RIVER QUADRANGLE, WASHINGTON

By EDWARD W. WOLFE and EDWIN H. MCKEE

ABSTRACT

The Grays River quadrangle in southwestern Washington is underlain by a thick sequence of Eocene to Miocene or younger marine sedimentary rocks and basaltic lavas that are part of a eugeosynclinal accumulation in western Washington and the Oregon Coast Range.

The oldest exposed rock unit, the Crescent Formation, consists mainly of tholeiitic pillow basalt of middle Eocene (Ulatisian) or possibly earliest late Eocene age (early Narizian). The basalt is chemically similar to the lower unit of the Siletz River Volcanics (lower and middle Eocene) of the Oregon Coast Range.

Unit A, overlying and perhaps intertonguing with the Crescent Formation, consists of about 2,000 feet of siltstone with some rhythmically interbedded sandstone probably deposited by turbidity currents. Likely source rocks are metamorphic and volcanic rocks such as those exposed in north-central Washington and adjacent British Columbia and Vancouver Island. Foraminifera indicate a late middle Eocene (late Ulatisian) or possibly earliest late Eocene age (early Narizian).

The next younger unit, B, comprises several thousand feet of marine tuffaceous siltstone, basaltic volcanic rocks, and a few beds of sandstone. Massive subaerial basalt flows, 2,000 feet thick or more, occur in the upper Grays River drainage area. In the Naselle River valley to the west, basaltic rocks of submarine origin interfinger with the tuffaceous siltstone. Foraminifera suggest a late Eocene age (Narizian and early Refugian). The uppermost part of the unit (Refugian) may be correlative with the lower part of the Lincoln Creek Formation, as mapped elsewhere in western Washington. Unit B accumulated in an offshore marine setting. The Grays River area was a volcanic center in the late Eocene.

Porphyritic basalt dikes, similar in lithology to unit B basalt, and larger bodies of diabase or gabbro intrude the Crescent Formation and units A and B in the northern part of the quadrangle. A late Eocene age is inferred.

The Lincoln Creek Formation, which overlies unit B, consists of two successive units of marine tuffaceous siltstone, each with a basal zone of basaltic and glauconitic sandstone. Fossils indicate an open-sea, offshore, sublittoral to bathyal depositional setting. Prior to its submergence in early Oligocene time, a subaerial mass of pre-Oligocene rock provided the basaltic detritus which makes up the lower part of the formation in the eastern part of the area. Foraminifera indicate that the Lincoln Creek is of latest

Eocene(?) and Oligocene age (Refugian and Zemorrian). Mollusks are referable to the Oligocene "Lincoln Stage" and to the "Blakeley Stage" of late Oligocene and early Miocene age.

The Astoria Formation (lower to middle Miocene) unconformably overlies the Lincoln Creek Formation. The predominant rock type (unit I), extensively exposed in the valleys of the Grays and Deep Rivers, is soft, argillaceous, carbonaceous, micaceous siltstone to very fine grained sandstone interpreted as an open-sea offshore facies. In the more eastern outcrops, the Astoria (unit II) consists of slightly coarser, more distinctly bedded, more fossiliferous strata with local accumulations of well-sorted crossbedded sandstone. These rocks are interpreted as a nearshore shallow-water facies. Interbedded sandstone and siltstone in the southwestern part of the Grays River quadrangle (unit III) may have accumulated in a deep-water, offshore setting.

Miocene to Pliocene(?) basalt flows overlie the Astoria Formation, and related dikes and sills intrude the Astoria Formation and older rocks. The flows and intrusives include the three petrochemical types recognized by others elsewhere in western Oregon and Washington as similar to basalt of the Yakima, late Yakima, and Pomona types of the Columbia Plateau.

INTRODUCTION

The Grays River quadrangle is in southwestern Washington, approximately 20 miles upstream from the mouth of the Columbia River (fig. 1). Mild climate and heavy rainfall (approximately 115 inches per year at Naselle, about 3 miles west of the map area) foster lush vegetation and deep and intensive weathering that impede geologic investigation. Outcrops are largely limited to stream courses and to roadcuts along the complex of logging roads that penetrates most of the quadrangle.

Geologic mapping of the Grays River quadrangle was undertaken by the U. S. Geological Survey during the summers of 1963 to 1966, as part of a cooperative program with the State of Washington. The resulting map, with a brief descriptive text, has been published by the State (Wolfe and McKee, 1968). This report is intended as a companion to that map.

Previously published literature on the geology of the Grays River area is limited to the pioneering stratigraphic and paleontologic studies of Weaver (1912, 1937). His monograph on the Tertiary stratigraphy and paleontology of western Washington and Oregon (1937) includes a generalized geologic map of the Grays River area. More recent detailed geologic studies of nearby areas in western Washington (Henriksen, 1956; Pease and Hoover, 1957; Rau, 1958, 1966, 1967; Snavely and others, 1958; Gower and Pease, 1965; Livingston, 1966; Wagner, 1967a, b) deal with stratigraphic sequences closely related to the succession in the quadrangle. In addition, accounts of the geologic history of western

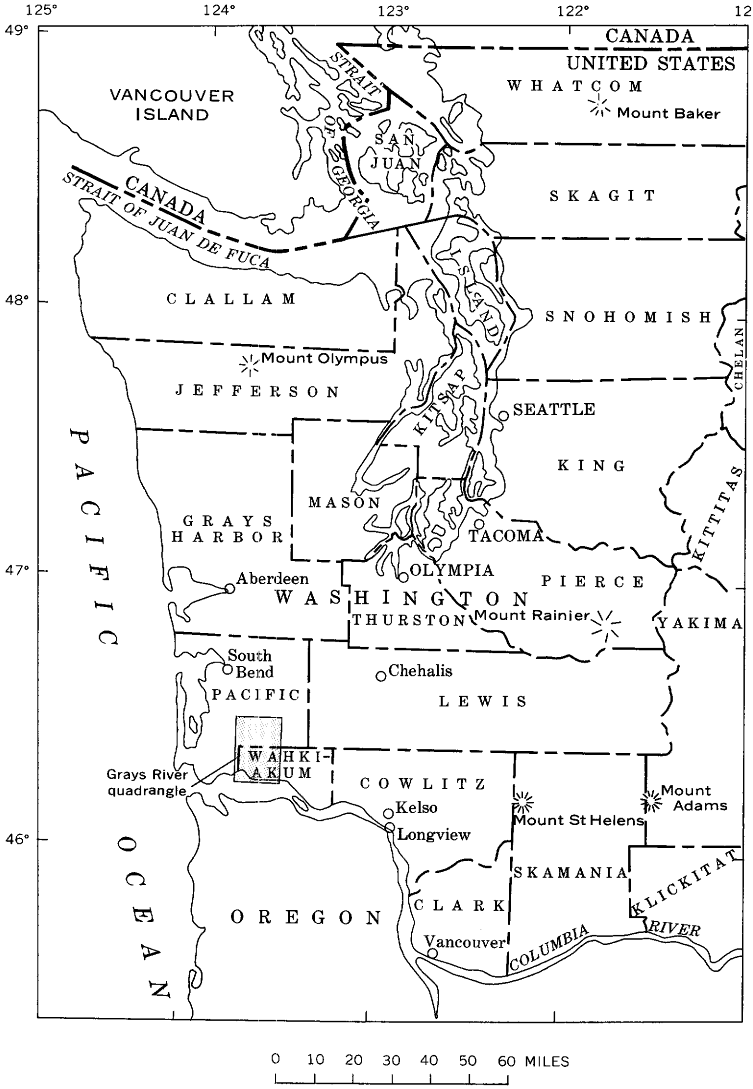

FIGURE 1.—Location of the Grays River quadrangle.

Washington and Oregon (Snavely and Wagner, 1963) and Washington (Wagner and Snavely, 1966) provide a regional historical framework for the geology of the Grays River area.

Weldon W. Rau of the Washington Division of Mines and Geology made all foraminiferal determinations and age designations; Warren O. Addicott of the U.S. Geological Survey made all molluscan identifications and correlations. Field assistance was rendered by A. R. Brown in 1963, M. D. Himes in 1964, and W. G. Gilbert in 1965. Special credit is due N. S. MacLeod, who mapped parts of the Astoria Formation and the basalt flows and intrusive rocks unit in 1966.

Petrographic analyses consisted largely of examination of thin sections and grain mounts, supplemented by X-ray diffraction where appropriate. Most of the modal analyses of igneous rocks are based on counts of 1,000 points in a thin section. Modal analyses of sandstones were determined by thin-section counts of 200 points. Because consistent distinction among feldspar types and quartz was difficult, point counts were supplemented by 200-grain counts on mounts stained to facilitate recognition of plagioclase and potassium feldspar. Grain counts were made with transmitted light to permit distinction of feldspars from clay minerals and lithic fragments that took the stains. Heavy minerals from the very fine sand (62–124 micron) fraction or from the coarse silt to very fine sand (30–124 micron) fraction were concentrated in tetrabromethane (sp gr 2.96), and 100 nonmicaceous, nonopaque grains per sample were identified. Little difference in heavy mineral distribution exists between the very fine sand fraction and the coarse silt to very fine sand fraction where these were compared for sandstone samples from the Grays River quadrangle.

TERTIARY SYSTEM

EOCENE SERIES

CRESCENT FORMATION

The oldest rock unit exposed in the Grays River quadrangle is a sequence of basaltic rocks called the Crescent Formation in accordance with the usage of Gower (1960). The sequence crops out in the relatively rugged highland areas in the northwestern and northeastern parts of the quadrangle and is probably more than 5,000 feet thick.

LITHOLOGY

The Crescent Formation consists mainly of aphanitic to fine-grained pillow basalt but also includes massive and columnar-jointed basalt, as well as small amounts of aquagene tuff and siltstone, locally with abundant radiolarian tests.

Pillows are well defined and range from about 1 to 3 feet in diameter. They are characterized in cross section by well-developed radial jointing and are rudely circular to elliptical in outline (fig. 2). In fresh exposure the pillow basalt looks greasy, and locally it is amygdaloidal.

Thin sections of typical Crescent basalt reveal that the rock is hypocrystalline and contains ophitic to subophitic plagioclase and augite (fig. 3). Point counts of several samples give the following compositional ranges: plagioclase 40 to 46 percent, augite 26 to 37 percent, olivine 0 to 3.5 percent, opaque minerals 2 to 8 percent, and fine-grained interstitial material, including altered glass and vesicle fillings, 14 to 22 percent.

Plagioclase (An_{57-70}) occurs as anhedral to subhedral laths ranging from about 0.1 to 1.5 mm (millimeter) in length. Some of the larger laths occur in cumulophyric clots as wide as 2.5 mm. Twinning and normal progressive zoning are common. Some plagioclase is altered to green montmorillonitic or chloritic clay minerals. Commonly, the feldspar core is intensely altered and the rim relatively fresh. Other types of alteration occur locally and include replacement of the plagioclase by analcite and alteration to oligoclase (about An_{30}) and heulandite. The known occurrences of the heulandite alteration are near faults.

Augite ($2V$ approximately 50°; N_y approximately 1.70) occurs as fresh anhedral to subhedral grains. Olivine, completely altered to clay minerals, makes up a small part of some specimens.

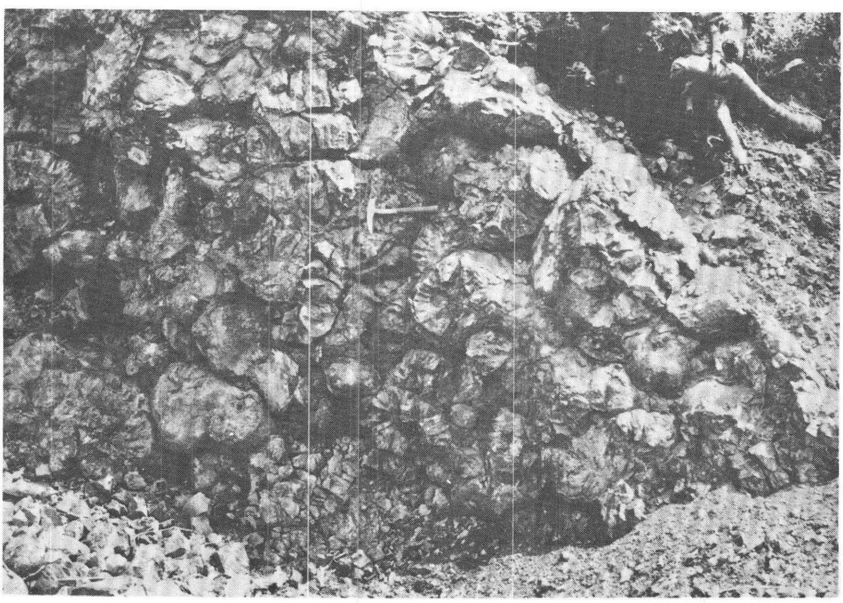

FIGURE 2.—Pillow basalt in the Crescent Formation (SW¼ sec. 11, T. 11 N., R. 7 W.).

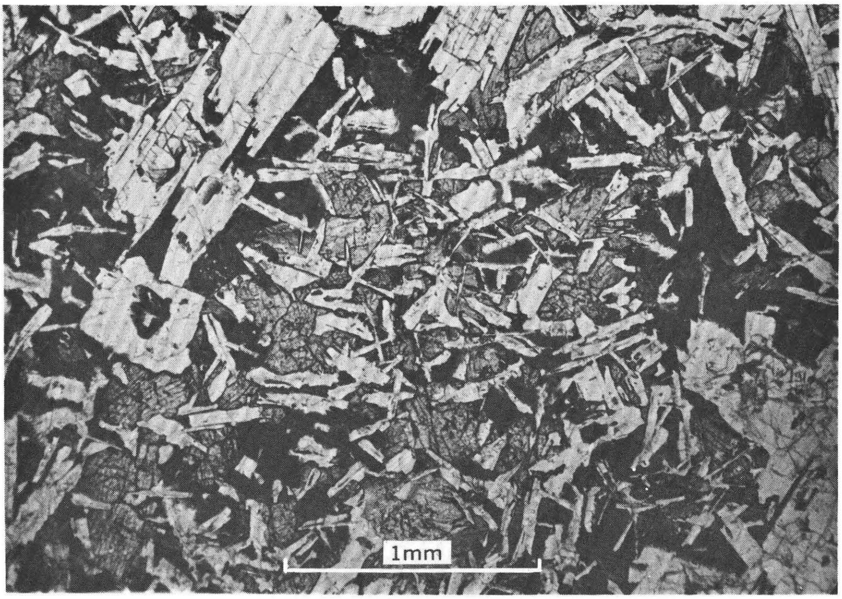

FIGURE 3.—Photomicrograph of Crescent basalt. Basalt consists predominantly of ophitic intergrowth of plagioclase and augite and contains scattered plagioclase phenocrysts, small crystals of magnetite and altered olivine, and patches of residuum with chlorophaeite(?) in part. Plane-polarized light.

Interstices are filled with altered glass, some of which encloses vesicles filled with a green to brown isotropic mineraloid (chlorophaeite?) that in places surrounds a core of montmorillonitic clay. The glass, partly altered to clay minerals, contains feldspar microlites and crystallites. Magnetite or ilmenite crystals are very abundant in the altered glass; they crosscut all parts of the basalt except the vesicle fillings.

Aquagene tuffs, exposed at the north edge of the quadrangle in the SW¼ sec. 24, T. 12 N., R. 8 W., and at the east edge of the quadrangle in the SW¼ sec. 12, T. 11 N., R., 6 W., consist of granules ranging from altered amygdaloidal glass to glassy basalt. Amygdule fillings, alteration products, and cementing agents include analcite, thomsonite, calcite, and montmorillonitic clay.

Chemical analyses and normative compositions of three samples of typical Crescent basalt are listed in columns 1 to 3 of table 1. As shown in figure 4 the samples are from widely separated localities. The basalts of the Crescent are typical tholeiites and are chemically similar to basalts of the lower unit of the Siletz River Volcanics of the Oregon Coast Range (table 1, columns 4A,

TABLE 1.—*Chemical analyses and normative compositions, in weight percent, of basalt of Crescent Formation and Siletz River Volcanics*

[Analyses recalculated to water-free basis. Nos. 1 to 3 (location shown in fig. 4) were analyzed by methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith]

	1	2	3	4A	4B
Chemical analyses					
SiO_2	49.3	48.6	49.2	49.0	48.3
Al_2O_3	15.8	14.9	14.9	14.5	14.6
Fe_2O_3	5.1	6.2	4.2	3.9	5.3
FeO	6.9	6.3	7.1	7.7	8.5
MgO	5.2	5.1	8.1	8.3	5.8
CaO	12.6	13.4	12.1	12.2	11.5
Na_2O	2.4	2.5	2.0	2.3	2.6
K_2O	.30	.17	.17	.17	.14
TiO_2	2.1	2.3	1.7	1.6	2.7
P_2O_5	.25	.30	.31	.15	.31
MnO	.25	.34	.20	.19	.25
CO_2	----	.05	----	----	----
H_2O-	1.2	1.7	2.2	----	----
H_2O+	1.1	1.2	2.0	----	----
Norms					
Q	4.3	4.4	2.4	----	2.8
Or	1.8	1.0	1.0	1.0	.8
Ab	19.9	21.0	16.9	19.5	22.0
An	31.5	28.9	31.2	28.7	27.8
Wo	12.2	14.7	11.1	12.9	11.4
En	13.0	12.6	20.1	19.7	14.4
Fs	5.4	3.3	7.2	8.2	7.2
Fo	----	----	----	.7	----
Fa	----	----	----	.3	----
Mt	7.4	9.0	6.1	5.7	7.7
Il	3.9	4.3	3.2	3.0	5.1
Ap	.6	.7	.7	.4	.7
Cc	----	.1	----	----	----
Normative plagioclase	An_{61}	An_{58}	An_{65}	An_{60}	An_{56}

1. Pillow basalt from quarry in NE¼SW¼ sec. 16, T. 11 N., R. 7 W. Field No. WGR63-379; USGS Lab. No. 162220.
2. Pillow basalt from quarry in NW¼NW¼ sec. 1, T. 11 N., R. 9 W. Field No. WoGR64-479; USGS Lab. No. 164283.
3. Massive basalt from NE¼NE¼ sec. 26, T. 12 N., R. 7 W. Field No. WoGR64-704; USGS Lab. No. 164294.
4. Tholeiitic basalt, lower unit of Siletz River Volcanics, central part of Oregon Coast Range. 4A, average of 3 analyses from older part of lower unit; 4B, average of 5 analyses from younger part of lower unit (from Snavely and others, 1968, table 3).

4B; fig. 12). Analysis 3 is nearly identical with average basalt from the older part of the lower unit of the Siletz River Volcanics (column 4A); analyses 1 and 2 are more similar to average basalt from the younger part (column 4B).

AGE AND CORRELATION

Foraminifera from siltstone interbeds in the Crescent Formation of the Grays River quadrangle (table 2) indicate a middle Eocene (Ulatisian of Mallory, 1959) or possibly earliest late Eocene age (early Narizan of Mallory, 1959). The Crescent Formation is lithologically correlative with the lower part of the Siletz River Volcanics (lower and middle Eocene) of western Oregon (Snavely and others, 1968).

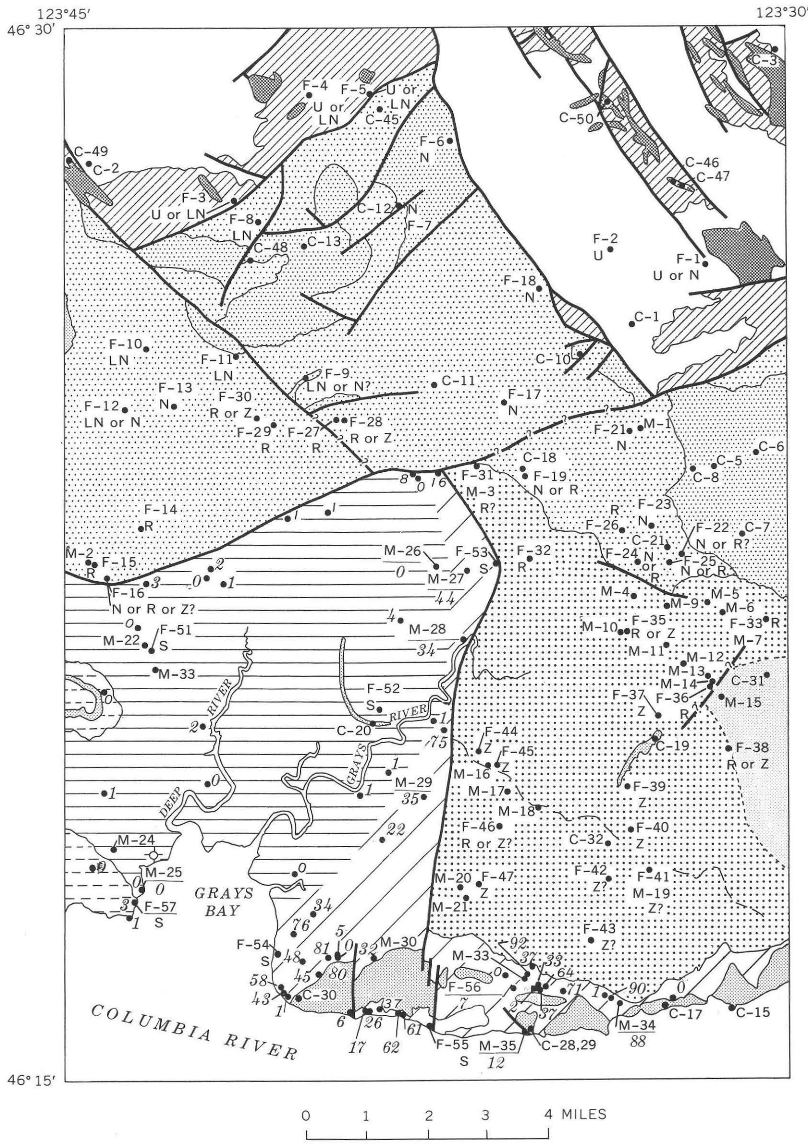

FIGURE 4.—Generalized geologic map of the Grays River quadrangle showing location of samples collected for fossils, for chemical analysis, or for heavy minerals.

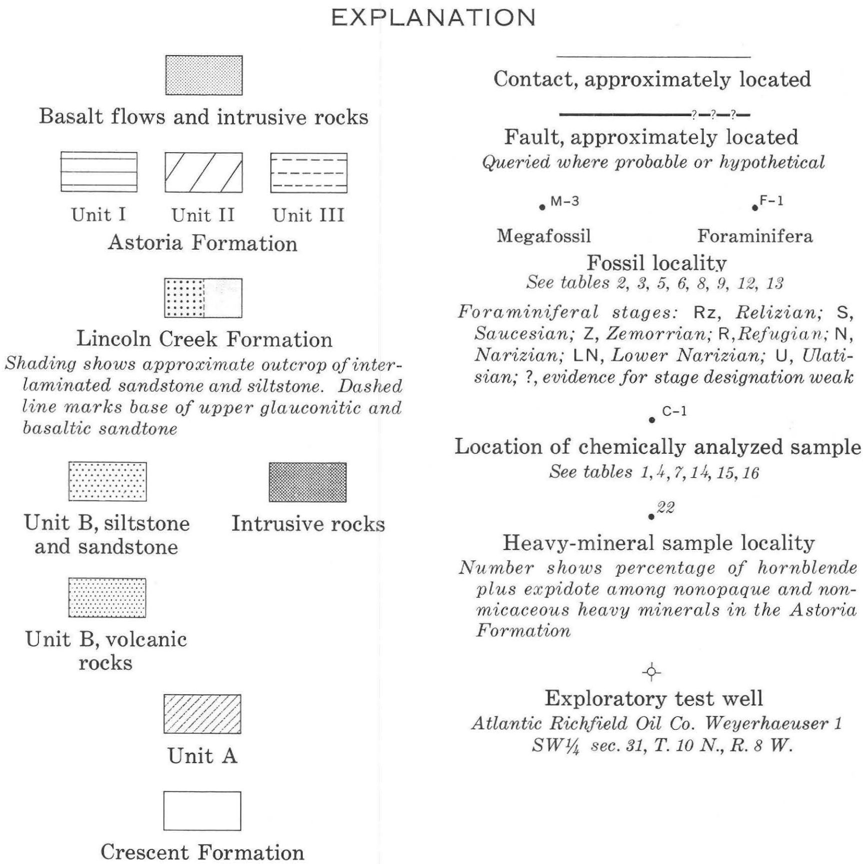

FIGURE 4.—Continued.

TABLE 2.—*Foraminifera from the Crescent Formation, Grays River quadrangle, Washington*

[Identifications by W. W. Rau. Fossil localities shown in fig. 4. C, common; F, few; R, rare]

Locality (fig. 4) Washington Div. Mines and Geology Lab. No	F-1 S-433	F-2 S-444
Anomalina sp	---	R
Asterigerina crassiformis Cushman and Siegfus	F	---
Bulimina cf. *B. lirata* Cushman and Parker	R	---
Cibicides sp	---	R
Cibides martinezensis malloryi Smith	C	---
Dentalina spp	---	R
Epistomina eocenica (Cushman and Hanna)	F	---
Eponides cf. *E. mexicana* (Cushman)	---	R
Gaudryina coalingensis (Cushman and G. D. Hanna)	---	C
Globigerina spp	F	C
Gyroidina orbicularis planata Cushman	R	---
Robulus spp	F	R
Valvulineria cf. *V. jacksonensis welcomensis* Mallory	R	---

PALEOGEOLOGIC SETTING

Volcanic rocks of the Crescent Formation in the Grays River area are part of a thick sequence of lower to middle Eocene basaltic volcanic rocks that accumulated in the axial part of a eugeosynclinal trough that extended from Vancouver Island to the Klamath Mountains. The thickness of the sequence is probably more than 10,000 feet in many parts of western Washington and Oregon and exceeds 15,000 feet in the Olympic Mountains (Snavely and Wagner, 1963, p. 3,4).

Qualifying the available microfaunal evidence as poor, W. W. Rau (written commun., 1966) noted that Foraminifera suggest accumulation of the Crescent Formation in shallow water, perhaps 300 feet deep, in an open-sea, offshore environment. The absence of basaltic sandstones and conglomerates and the predominance of pillow basalt suggest that the water was too deep for local volcanic accumulations to reach above sea level within the mapped area.

UNIT A

A unit of siltstone and interbedded sandstone, which may be as thick as 2,000 feet, overlies and perhaps intertongues locally with the upper part of the Crescent Formation. The unit, informally designated unit A, is exposed in the northwestern and northeastern parts of the quadrangle.

LITHOLOGY

Siltstone, the predominant type of rock in unit A, is well indurated, thin bedded, and dark gray where freshly exposed. It consists of angular silt-sized quartz, feldspar, and lithic grains, as well as minute mica flakes in a chlorite or vermiculite matrix.

Sandstone beds, rhythmically alternating with siltstone, range in thickness from less than a foot to more than 10 feet (fig. 5). In fresh exposures the sandstone is greenish gray, but in most outcrops it is weathered to shades of yellow or brown. The sandstone is very fine to medium grained with abundant interstitial clay and randomly scattered mica flakes. Coarser sand and granules occur locally. Typically, the sandstone beds have no visible internal structure. Graded bedding is visible in some outcrops, but it is usually difficult to recognize where coarse detritus is absent. Small-scale crossbedding occurs locally. The basal contacts of the sandstone beds are always sharp; sole marks are uncommon.

Inspection of thin sections indicates that the sandstone is angular very fine to fine sand in a clay-rich matrix. In some rocks the

FIGURE 5.—Rhythmically alternating sandstone and siltstone of unit A (SW¼SE¼ sec. 33, T. 12 N., R. 8 W.).

sand is coarser, and grains become more rounded as grain size increases.

Modal analyses of seven unit A sandstone samples have the average composition shown below. Typically, quartz constitutes about one-quarter to one-third of the rock. Monocrystalline quartz, commonly strained, is slightly more abundant than the polycrystalline varieties, which range from cryptocrystalline fragments (chert?) to coarser interlocking mosaics of probable metamorphic origin. Feldspar, also one-quarter to one-third of the rock, consists primarily of sodic plagioclase and a smaller amount of potash feldspar. Much of the feldspar does not show twinning

	Volume percent (avg.)
Monocrystalline quartz	16
Polycrystalline quartz	11
Potassium feldspar	5
Plagioclase	21
Mica and chlorite	7
Metamorphic rocks	2
Volcanic rocks	8
Volcanic(?) rocks	10
Matrix	15
Other	4
	99

in thin section, and consistent distinction among feldspar types and quartz is difficult. Relative proportions of quartz and the feldspars, determined from stained grain mounts, are plotted in figure 6. Lithic fragments include small quantities of schistose metamorphic grains, fairly abundant obviously volcanic clasts, and clasts whose alteration, small size, and (or) fine texture preclude unequivocal classification. Many of the latter are probably of volcanic origin. Muscovite flakes and chlorite clasts are scattered, and crumpled biotite grains are abundant.

Although sharp grain boundaries occur, many clasts have vague or intricately interdigitated boundaries with the matrix. Biotite and volcanic clasts grade into the matrix, which to some extent is a product of the alteration of unstable clasts. X-ray diffraction analyses indicate that the matrix is predominantly a clay mineral intermediate between chlorite and vermiculite. In a few specimens the matrix is calcite.

The heavy mineral suite is characterized by an abundance of epidote, or epidote and green or blue-green hornblende. In 15 of 17 samples, epidote and hornblende total more than 80 percent of the nonopaque, nonmicaceous heavy minerals. The other heavy

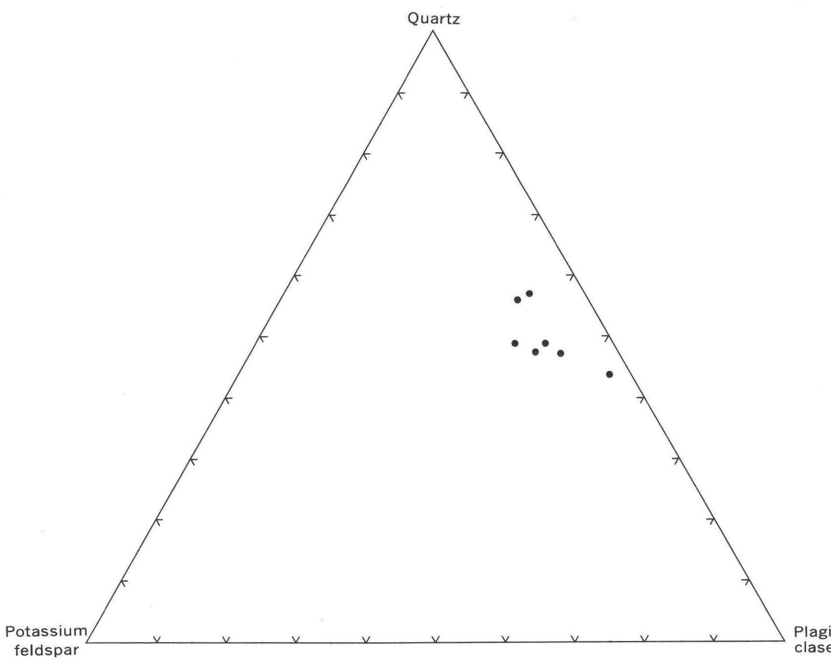

FIGURE 6.—Relative proportions of quartz, potassium feldspar, and plagioclase in unit A sandstone.

minerals are zircon, garnet, tourmaline, sphene, apatite, staurolite, and rutile.

Interbedded siltstone and volcanic sandstone which occur north of the headwaters of Sweigiler Creek, near the eastern border of the quadrangle, are included in unit A. The sandstones are volcanic wackes with clasts of plagioclase and basalt. Beds, some of which are graded, are massive and range from a few inches to about 2 feet in thickness.

AGE AND CORRELATION

Foraminifera from siltstones in unit A (table 3) in the north-central part of the quadrangle indicate an age of late middle Eocene (late Ulatisian of Mallory, 1959) or possibly earliest late Eocene (early Narizian of Mallory, 1959). Unit A is continuous with strata mapped as rhythmically bedded sandstone and siltstone in the Raymond quadrangle (Wagner, 1967a) and at least in part is also continuous with strata included with the lower member of the McIntosh Formation in the southwestern corner of the Doty-Minot Peak area (Pease and Hoover, 1957). Close tem-

TABLE 3.—*Foraminifera from unit A, Grays River quadrangle, Washington*

[Identifications by W. W. Rau. Fossil localities shown in fig. 4. C, common; F, few; R, rare; ?, identifications questionable]

Locality (fig. 4)	F–3	F–4	F–5
Washington Div. Mines and Geology Lab. No	4010	3921	4268
Alabamina wilcoxensis Toulmin	R	--	--
Allomorphina macrostoma Karrer	--	R	--
Anomalina sp	F	--	--
Asterigerina crassiformis Cushman and Siegfus	R	F	--
Bulmina pupoides d'Orbigny	F	F	--
Cassidulina globosa Hantken	--	--	?
Cibicides sp	R	--	--
cf. *C. venezuelanus* Nuttall	?	--	--
Dentalina spp	F	--	F
Dorothia principiensis Cushman and Bermudez	--	--	F
Epistomina eocenica (Cushman and Hanna)	--	R	--
Globigerina spp	C	F	C
Gyroidina orbicularis planata Cushman	--	R	F
simiensis Cushman and McMasters	--	--	F
Nodosaria cf. *N. arundinea* Schwager	--	F	--
Pleurostomella acuta Hantken	R	--	--
Pullenia eocenica Cushman and Siegfus	--	--	R
Robulus spp	F	F	C
Silicosigmoilina californica Cushman and Church	R	--	--
Spiroplectammina directa (Cushman and Siegfus)	C	R	C
Tritaxilina colei Cushman and Siegfus	--	--	C
Uvigerina cf. *U. churchi* Cushman and Siegfus	--	--	R
garzaensis Cushman and Siegfus	R	--	--
Valvulineria cf. *V. jacksonensis welcomensis* Mallory	--	--	?

poral affinity with the Crescent Formation of the southern part of the Olympic Peninsula is suggested by the occurrence in unit A of the following Foraminifera, restricted to the Crescent in the Satsop area (Rau, 1966, p. 23, 24) and in the Wynoochee Valley quadrangle (Rau, 1967):

Cibicides cf. *C. venezuelanus* Nuttall
Dorothia principiensis Cushman and Bermudez
Gyroidina simiensis Cushman and McMasters
Pullenia eocenica Cushman and Siegfus
Silicosigmoilina californica Cushman and Clark
Spiroplectammina directa (Cushman and Siegfus)
Tritaxilina colei Cushman and Siegfus
Uvigerina cf. *U. churchi* Cushman and Siegfus

Except for *Epistomina eocenica* (Cushman and Hanna), none of the 41 species appearing first in sedimentary rocks of late Eocene age in the Satsop area (Rau, 1966, p. 25–27) are present in unit A. Many of these Foraminifera do occur in unit B.

Unit A is superficially similar to the Tyee Formation (middle Eocene), which overlies the Siletz River Volcanics in the central part of the Oregon Coast Range (Snavely and others, 1964); it may be approximately correlative with either the Tyee or the overlying mudstones, which are assigned to Mallory's (1959) upper Ulatisian or lower Narizian Stages (Snavely and others, 1964, p. 465).

PALEOGEOLOGIC SETTING

Rhymthmic repetition of sandstone beds, some of which are graded, suggests that the unit A sandstones may have been deposited by turbidity currents. Although he considered the evidence poor, Rau (written commun., 1966) noted that the presence of certain Foraminifera suggests deposition of unit A siltstone in an open-sea, offshore environment at 600- to 3,000-foot depths which would be compatible with a turbidity current origin for the sandstones.

The mineralogy of unit A suggests that the source areas included volcanic and metamorphic rocks, such as the amphibolites and hornblende gneisses common in the pre-Tertiary orogenic belt exposed in the Klamath Mountains of southwestern Oregon and in the Cascade Range in northern Washington and British Columbia.

Since the composition of unit A is different from that of the Tyee Formation, a turbidite sequence derived mostly from the Klamath Mountains, unit A probably had a different source. According to Snavely, Wagner, and MacLeod (1964) the Tyee contains 3 to 20 percent plagioclase, compared with 18 to 28 percent in unit A. Plagioclase in the Tyee is commonly euhedral and shows pronounced oscillatory zoning, unlike plagioclase in unit A, and hornblende is the only nonopaque heavy mineral recognizable in more than trace amounts in thin sections of Tyee sandstone (Snavely and others, 1964, p. 469–471). Cursory examination of several heavy mineral separates from the Tyee indicates that epidote, while common, is not preponderant as in unit A.

Likely sources for unit A sandstone are north-central Washington and adjacent British Columbia and Vancouver Island. Wagner and Snavely (1966, p. 40–42) suggest that middle Eocene turbidites in southwestern Washington (unit A) may share the Vancouver Island source of sandstones of the northern Olympic Peninsula. Because heavy mineral separates from a suite of sandstones that H. D. Gower collected in the northern Olympic Peninsula commonly show a preponderance of epidote, they support this suggestion.

UNIT B

The next younger map unit, informally designated unit B, consists of several thousand feet of marine tuffaceous siltstone, a few beds of sandstone, and volcanic rocks. The absence of distinctive marker beds and lack of information about structural details prevent a precise determination of the thickness, but more than 5,000 feet seems likely. The contact with the older rocks, where observed, is a fault.

LITHOLOGY

SILTSTONE

The most widespread rock type in unit B is marine tuffaceous siltstone, which is well indurated, well stratified, and generally some shade of gray or greenish gray. Common calcareous concretions range from spheres about an inch in diameter to elongate lenticular masses as much as 1 foot thick and many feet long.

The siltstone (fig. 7) contains silt to very fine sand-sized detritus occurring as dispersed grains as lenticular laminae in a montmorillonitic matrix. The most abundant constituents of silt and sand size are quartz, feldspar, volcanic fragments, and glass shards altered to heulandite. Megafossils are rare, but Foraminifera are abundant and are commonly visible in hand specimens.

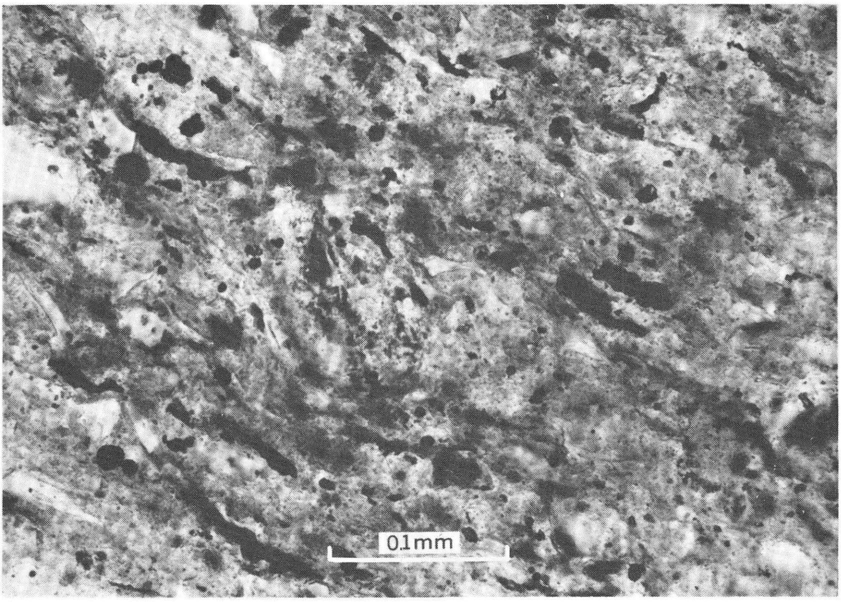

FIGURE 7.—Photomicrograph of unit B siltstone. Contains quartz, feldspar, lithic fragments, and glass shards in a matrix of montmorillonitic clay. Opaque fragments are iron-sulfide nodules and carbonaceous clasts. Plane-polarized light.

SANDSTONE

Sandstone is a minor constituent of unit B. It includes a massive, fine- to medium-grained, friable arenite approximately 200 feet thick that rests on the subaerial volcanic rocks in the eastern part of the quadrangle and grades upward into marine tuffaceous siltstone in the upper part of unit B. Similar sandstone, as well as basaltic and glauconitic sandstone, occurs in scattered outcrops elsewhere. In a few localities, particularly in the north-central part of the quadrangle and in the Naselle River channel near the west edge of the quadrangle (sec. 12, T. 10 N., R. 9 W.) a very fine grained sandstone is interlaminated with siltstone. Parallel lamination with concentrations of mica and carbonaceous detritus on the bedding surfaces is characteristic. Small-scale crossbedding and structures produced by sedimentary loading occur locally.

Unit B sandstone is predominantly angular very fine to medium-grained quartz and feldspar with abundant mica flakes and sparse lithic fragments. An estimate of average composition based on point counts on 10 thin sections supplemented by results from stained grain mounts is shown below:

	Volume percent (avg.)
Monocrystalline quartz	18
Polycrystalline quartz	13
Potassium feldspar	10
Plagioclase	15
Mica and chlorite	9
Metamorphic rocks	2
Volcanic rocks	3
Volcanic(?) rocks	4
Matrix	24
Other	2
	100

Matrix, including detrital silt and clay and altered unstable clasts, constitutes from less than 1 to more than 40 percent of the volume of unit B sandstones. Hence, the average percentages shown here represent a wide range of values; however, they are representative of the relative proportions that occur among the clastic components of unit B sandstones. Except for local basaltic sandstones, in which the volcanic clasts resemble unit B basalt, unit B sandstones have significantly fewer volcanic clasts than unit A sandstones. Comparison of figure 8, a triangular plot of quartz, potassium feldspar, and plagioclase, with a similar plot for unit A (fig. 6) shows that unit B sandstones are more varied in composition and significantly richer in potassium feldspar relative to quartz and plagioclase than unit A sandstones.

Generally, the sandstones can be separated into two distinct groups on the basis of heavy mineral composition. In one group, represented by 14 of 22 samples counted, epidote constitutes from 25 to 95 percent of the heavy mineral fraction. Other heavy minerals in this group, which includes the mapped sandstone unit overlying the subaerial volcanic rocks, are green or blue-green amphibole, zircon, garnet, sphene, apatite, tourmaline, rutile, and staurolite. In the second group, represented by six samples, amphibole is absent, and epidote constitutes 2 percent or less of the nonopaque heavy minerals. In this group zircon, garnet, sphene, and apatite are the most abundant heavy minerals) constituting 62 to 92 percent of the nonopaque heavy minerals. Other heavy minerals include tourmaline, staurolite, rutile, and monazite. Figure 8 indicates that the epidote-rich sandstones have relatively less quartz and more feldspar than the epidote-poor sandstones.

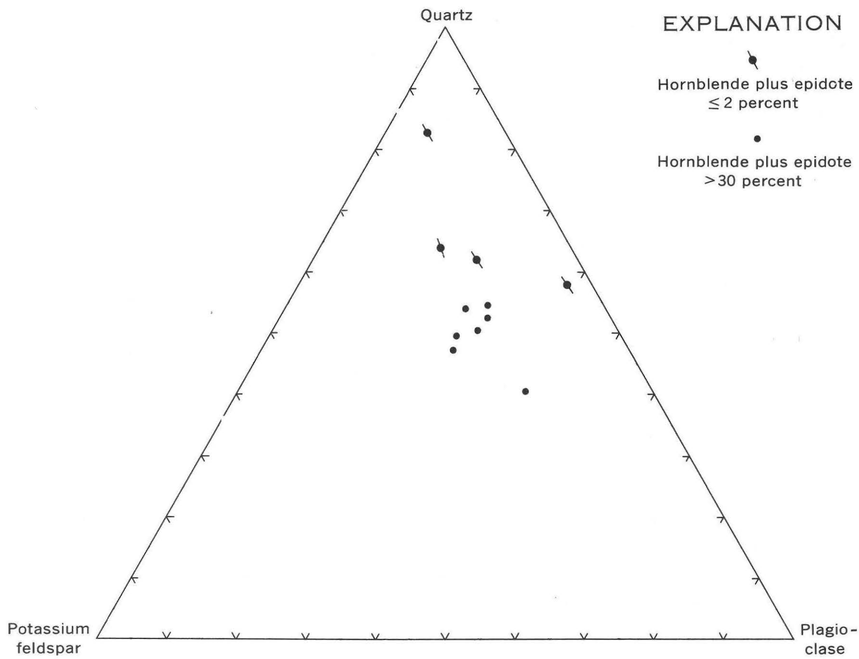

FIGURE 8.—Relative proportions of quartz, potassium feldspar, and plagioclase in unit B sandstones.

VOLCANIC ROCKS

The volcanic rocks of unit B are mainly massive lava flows of subaerial origin in the upper reaches of Grays River and aquagene tuff and flow breccia of probable marine origin in the Naselle River valley. The massive flows of the upper Grays River drainage area are relatively fresh porphyritic basalt and andesitic basalt with a small amount of tuff and volcanic breccia. Bright red zones of oxidized tuff or altered lava, some as thick as 15 feet, occur locally. At the base of the sequence the massive flows grade downward into volcanic breccia, tuff, and volcanic sandstone that are interbedded with marine siltstone of unit B. Oyster fragments occur in the tuffaceous marine rocks immediately below the subaerial basalt. The total thickness of massive basalt is unknown, but it is probably at least 2,000 feet.

Typical massive basalt in the upper Grays River drainage area contains phenocrysts of plagioclase (An_{75-85}) that are twinned, progressively zoned, and up to 3 mm long (fig. 9), as well as subhedral augite (N_y approximately 1.70; $2V=41°–56°$) and subhedral to euhedral olivine altered to clay minerals and chlo-

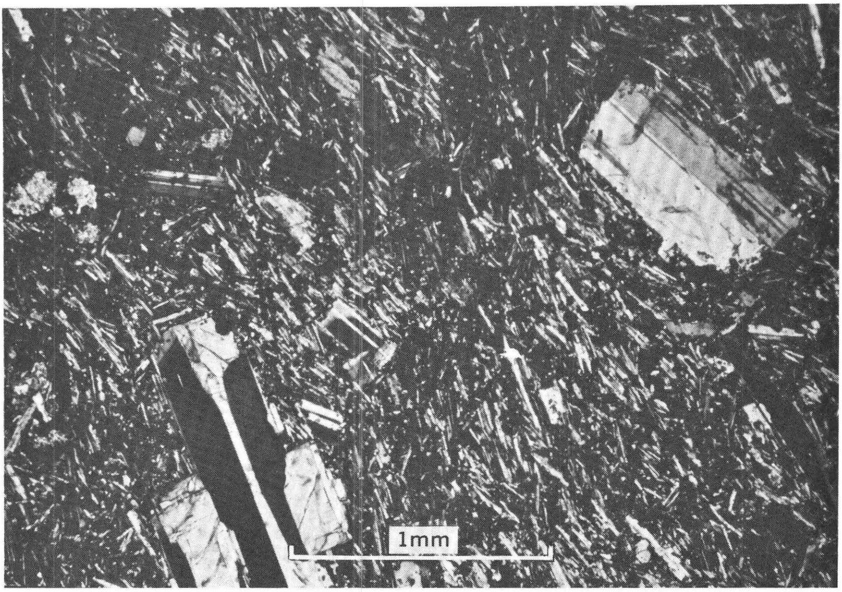

FIGURE 9.—Photomicrograph of unit B subaerial basalt. Plagioclase phenocrysts in intergranular groundmass of small subparallel crystals of plagioclase with interstitial clinopyroxene, magnetite or ilmenite, and minor residuum. Crossed polarizers.

rophaeite(?). The groundmass is intergranular in texture and is commonly trachytic. It consists of subhedral plagioclase crystals (An_{40-52}), interstitial granules of clinopyroxene and opaque minerals, and a small amount of residuum largely represented by clay minerals and mineraloids. The phenocrysts, particularly plagioclase and augite, often occur in cumulophyric clots and are commonly slightly embayed by the groundmass. Relative proportions of the mineral constituents vary slightly, but an average of five specimens gives the following approximate compositions: plagioclase phenocrysts, 4 percent; groundmass plagioclase, 38 percent; augite phenocrysts, 1 percent; clinopyroxene microlites, 35 percent; olivine phenocrysts, 1 percent; opaque minerals, 17 percent; residuum, 4 percent.

Basaltic rocks of submarine origin interfinger with marine tuffaceous siltstone in the valleys of the Naselle River and Salmon Creek. They also crop out in the North Nemah River valley in the northwest part of the quadrangle and in and near the headwaters of Hull Creek in the east-central part of the quadrangle. The lowest rocks penetrated by the Atlantic Richfield Co.–Weyerhaeuser

FIGURE 10.—Well-bedded aquagene tuff of unit B exposed in the bank of the Naselle River (NW¼SE¼ sec. 17, T. 11 N., R. 8 W.).

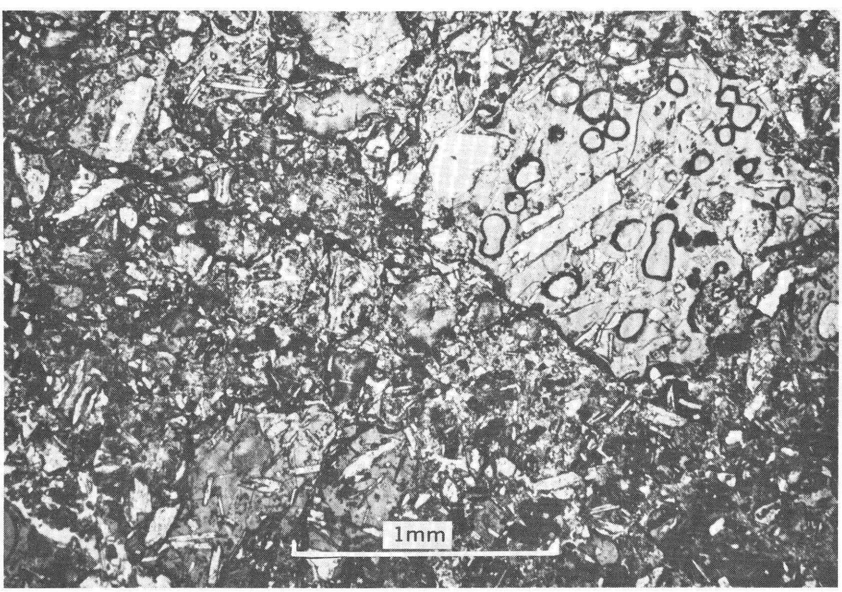

FIGURE 11.—Photomicrograph of unit B aquagene tuff. Clasts of amygdaloidal glassy basalt in a matrix of comminuted glass-rich basaltic debris. Plane-polarized light.

1 well on the west shore of Grays Bay consist of approximately 800 feet of alternating siltstone and porphyritic amygdaloidal basalt, which is interpreted as submarine volcanic rock of unit B.

The submarine volcanic rocks are mainly massive to well-bedded dark-gray to olive-gray well-indurated aquagene tuff (fig. 10) exposed in steep-sided gorges along the Naselle River and its tributaries. The tuff is mostly angular clasts of extremely amygdaloidal volcanic rock ranging from altered basaltic glass to glassy or very fine grained porphyritic basalt (fig. 11). Crystals of plagioclase and augite also occur as clasts. Some plagioclase occurs as cumulophyric masses similar to those in the massive flows of the Grays River valley. Calcite and analcite are the cementing agents; calcite, analcite, or montmorillonitic clay fill the amygdules and occur as alteration products of the glass. In some specimens plagioclase has been replaced by analcite.

Locally the volcanic sequence contains extremely amygdaloidal pillow basalt resembling basalt clasts in the aquagene tuff. The volcanic sequence also contains a small amount of basaltic sandstone that differs from the tuff mainly in that the clasts are rounded. The aquagene tuff interfingers with tuffaceous siltstone and grades laterally through siltstone rich in coarse volcanic debris to normal marine tuffaceous siltstone.

Relatively unaltered nonamygdaloidal basalt similar in lithology to the massive flows of the Grays River valley is present locally among the submarine volcanic rocks. It occurs most commonly as flow breccia, but in places it is pillowed or massive and may include some small intrusive bodies. Typically the basalt is porphyritic, often cumulophyric, with phenocrysts of plagioclase (An_{70-85}), augite (N_y approximately 1.70; $2V=43°–52°$), and altered olivine in an intergranular, often strongly trachytic groundmass of plagioclase (approximately An_{50}), clinopyroxene, and opaque minerals. An approximate average composition is plagioclase phenocrysts, 4 percent; groundmass plagioclase, 33 percent; augite phenocrysts, <1 percent; clinopyroxene microlites, 30 percent; olivine, <1 percent; opaque minerals, 19 percent; residuum, 12 percent.

Chemical analyses of unit B basalt are shown in table 4. Columns 5 to 9 are analyses of the massive subaerial basalts from the upper Grays River drainage area. Columns 10 to 13 are analyses of relatively unaltered nonamygdaloidal basalt from volcanic breccia and pillow basalt in the submarine volcanic rocks. Column 14 is an analysis of altered porphyritic to cumulophyric basalt at a depth of approximately 8,530 feet in the Atlantic Richfield Co.–

TABLE 4.—*Chemical analyses and normative compositions, in weight percent, of unit B basalt*

[Analyses recalculated to water-free basis. Analyses were done by methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith. Location of Nos. 5–8, 10–13 shown in fig. 4]

	5	6	7	8	9	10	11	12	13	14
Chemical analyses										
SiO_2	50.6	51.1	50.8	48.6	49.4	49.1	49.0	48.3	46.7	47.7
Al_2O_3	16.8	15.4	15.7	15.8	15.2	13.8	16.4	16.0	15.8	16.4
Fe_2O_3	6.3	7.1	6.0	5.5	3.4	3.7	3.8	4.9	6.6	6.6
FeO	6.3	6.5	6.8	7.6	9.9	11.6	7.4	8.4	7.6	6.8
MgO	2.7	3.2	3.3	4.7	4.7	4.1	5.5	4.6	5.0	5.7
CaO	8.6	8.1	8.2	10.3	10.4	9.7	11.9	10.6	10.4	9.4
Na_2O	3.6	3.2	3.6	2.8	2.7	2.9	2.6	2.8	2.5	3.9
K_2O	1.1	.93	1.2	.86	.59	.36	.29	.36	.28	.29
TiO_2	3.1	3.6	3.6	3.3	3.3	3.8	2.6	3.4	4.0	2.6
P_2O_5	.64	.60	.75	.46	.46	.77	.39	.46	.60	.47
MnO	.22	.22	.19	.21	.18	.22	.15	.21	.53	.14
CO_2	.10	.18	-----	-----	.07	.07	-----	-----	.09	-----
H_2O-	.75	.84	1.4	1.0	.66	.68	.85	.90	2.0	1.0
H_2O+	.95	.94	.80	.67	1.2	1.3	1.1	1.3	1.0	4.6
Norms										
Q	7.0	11.2	6.8	3.8	3.7	5.1	2.6	4.0	5.6	-----
Or	6.6	5.5	7.3	5.1	3.5	2.1	1.7	2.1	1.6	1.7
Ab	30.2	26.7	30.3	23.3	22.4	24.2	21.6	23.4	20.9	33.4
An	26.6	25.1	23.0	28.2	27.8	23.7	32.5	30.2	31.1	26.2
Wo	4.6	4.1	5.3	8.3	8.5	7.9	10.1	8.0	6.7	7.2
En	6.6	7.9	8.2	11.7	11.7	10.2	13.7	11.5	12.3	10.7
Fs	1.8	.6	1.9	4.5	10.3	12.5	6.6	6.2	2.9	2.4
Fo	-----	-----	-----	-----	-----	-----	-----	-----	-----	2.4
Fa	-----	-----	-----	-----	-----	-----	-----	-----	-----	.6
Mt	9.2	10.3	8.8	8.0	4.9	5.3	5.5	7.1	9.6	9.6
Il	5.8	6.8	6.8	6.2	6.2	7.2	4.8	6.4	7.6	4.9
Ap	1.5	1.4	1.8	1.1	1.1	1.8	.9	1.1	1.4	1.1
Cc	.2	.4	-----	-----	.2	.2	-----	-----	.2	-----
Normative plagioclase	An_{47}	An_{48}	An_{43}	An_{55}	An_{55}	An_{50}	An_{60}	An_{56}	An_{60}	An_{44}

5. Massive basalt from NE¼NE¼ sec. 34, T. 11 N., R. 7 W. Field No. WGR63–383; USGS Lab. No. 162222.
6. Massive basalt from SW¼SE¼ sec. 26, T. 11 N., R. 7 W. Field No. WGR63–384; USGS Lab. No. 162223.
7. Massive basalt from SE¼NW¼ sec. 2, T. 10 N., R. 7 W. Field No. WGR64–430; USGS Lab. No. 162873.
8. Massive basalt from NE¼NW¼ sec. 34, T. 11 N., R. 7 W. Field No. WGR63–382; USGS Lab. No. 162221.
9. Columnar basalt from center of sec. 30, T. 11 N., R. 6 W., Skamokawa quadrangle. Field No. WGR63–402; USGS Lab. No. 162225.
10. Basalt breccia from NW¼NE¼ sec. 20, T. 11 N., R. 7 W. Field No. WGR63–137; USGS Lab. No. 162216.
11. Basalt breccia from quarry in SE¼SE¼ sec. 23, T. 11 N., R. 8 W. Field No. WGR63–355; USGS Lab. No. 162219.
12. Basalt breccia from SE¼SW¼ sec. 2, T. 11 N., R. 8 W. Field No. WGR63–410; USGS Lab. No. 162226.
13. Isolated pillow in basalt breccia from NE¼SE¼ sec. 9, T. 11 N., R. 8 W. Field No. WoGR64–504; USGS Lab. No. 164286.
14. Zeolitized porphyritic basalt from depth of approximately 8,530 feet in Richfield-Weyerhaeuser 1 well, SE¼SW¼ sec. 31, T. 10 N., R. 8 W. Field No. SR61–187; Lab. No. 160087. (Published with permission of Atlantic Richfield Co.).

Weyerhaeuser 1 well on the west shore of Grays Bay. In this rock, phenocrysts of augite, altered olivine, and plagioclase extensively altered to thomsonite occur in a fine-grained, somewhat trachytic, intergranular groundmass with scattered amygdules. The rock is fractured; calcite, thomsonite, and chlorite fill fractures and amygdules. The undersaturated normative composition presumably reflects addition of soda, suggested by the unusually high soda content (3.9 percent Na_2O) in the chemical analysis.

As a group, unit B volcanic rocks most nearly approximate normal tholeiitic basalt and average tholeiitic andesite in the chemical grouping of Nockolds (1954, tables 6 and 7). Although tholeiitic basalt occurs in both the submarine and subaerial flows, the latter include some slightly more silicic and alkalic rocks that might be distinguished as andesitic basalts (columns 5 to 7, table 4 this report). These contain more normative quartz (6.8 to 11.2 percent) than the associated rocks (2.6 to 5.6 percent); more normative potash feldspar (5.5 to 7.3 percent) than the associated rocks (1.6 to 5.1 percent); a more sodic normative plagioclase (An_{43-47}) than the associated rocks (An_{50-60}); and more normative salic minerals (67.4 to 70.4 percent) than the associated rocks (55.0 to 60.3 percent).

Unit B volcanic rocks are richer than Crescent basalt (table 1) in alkalis, titania, and phosphate, and poorer in calcium and magnesium oxides. However, they range from tholeiitic basalt (table 4, column 11) chemically very much like Crescent basalt to andesitic basalt (table 4, columns 5 to 7). Figure 12 illustrates some of the chemical relationships among the igneous rocks of the Grays River area. Except for three rocks altered by addition of soda, basaltic rocks of the Crescent Formation, unit B, and the intru-

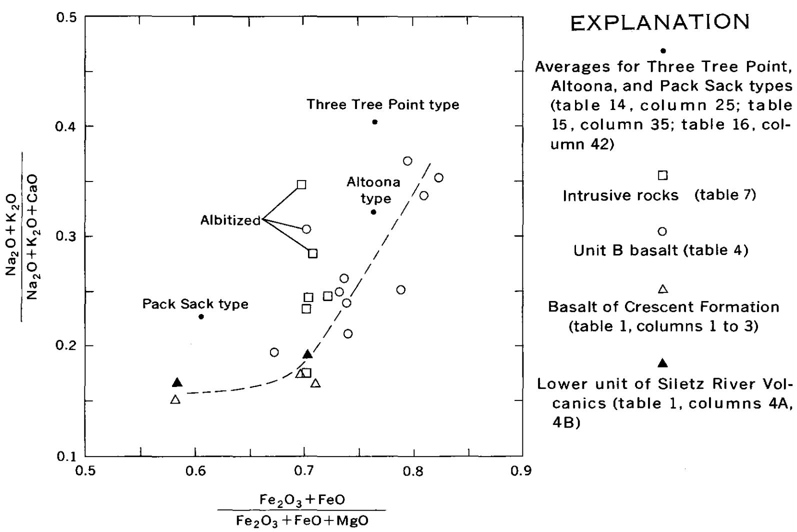

FIGURE 12.—Chemical relationships among basaltic rocks of the Grays River area.

TABLE 5.—*Foraminifera from unit*

[Identifications by W. W. Rau, Fossil localities shown in fig. 4, except

Fossil localities Washington Div. Mines and Geology Lab. No.	F–6 S-431	F–7 S-428	F–8 4024	F–9 S-430	F–10 4020	F–11 4021	F–12 4019	F–13 4243	F–14 4014	F–15 4251
Alabamina wilcoxensis Toulmin	--	--	--	--	--	--	--	--	--	--
Allomorphina macrostoma Karrer	--	C	--	F	R	F	?	?	--	--
Angulogerina hannai Beck	F	--	--	--	--	--	--	--	--	--
Astacolus cf. *A. barksdalei* Beck	--	--	--	R	--	--	--	--	--	--
Asterigerina crassaformis Cushman and Siegfus	--	--	--	--	?	--	--	--	--	--
Baggina teninoensis Rau	--	C	--	--	?	--	--	--	--	--
Bolivina basisenta Cushman and Siegfus	--	--	--	--	--	--	--	--	--	--
cf. *B. jacksonensis* Cushman and Applin	--	--	--	--	--	--	--	--	R	--
Bulimina corrugata Cushman and Siegfus	--	--	C	--	--	--	--	--	--	--
cf. *B. jacksonensis* Cushman	--	--	C	--	--	--	--	--	--	--
microcostata Cushman and Parker	--	C	--	--	--	--	--	--	--	--
pachecoensis Smith	--	--	--	--	--	--	R	--	--	--
pupoides d'Orbigny	--	F	C	--	C	--	--	--	--	--
schencki Beck	--	--	--	--	--	--	--	--	--	--
sculptilis laciniata Cushman and Parker	--	--	--	--	--	--	--	R	--	--
Cancris joaquinensis Smith	--	--	--	--	--	--	--	--	--	--
Cassidulina globosa Hantken	?	--	--	--	?	--	--	--	--	?
cf. *C. globosa* Hantken	--	--	--	--	--	--	--	--	--	--
Chilostomella cf. *C. oolina* Schwager	--	--	--	--	--	R	--	--	--	--
Cibicides sp.	--	--	C	--	R	--	F	--	--	F
elmaensis Rau	--	--	--	--	--	--	--	--	--	--
hodgei Cushman and Schenck	--	--	--	--	--	--	--	--	--	--
cf. *C. laimingi* Mallory	--	--	--	--	--	--	R	--	--	--
cf. *C. pachecoensis* Smith	--	--	--	--	--	--	--	R	--	--
Dentalina spp	--	--	R	F	--	--	F	F	F	F
sp. B of Rau, 1948	--	--	--	--	--	--	--	--	--	--
sp. C of Rau, 1948	--	--	--	--	--	--	--	--	--	--
consobrina d'Orbigny	--	--	--	--	--	--	--	--	--	--
cf. *D. consobrina* d'Orbigny	--	--	--	--	--	--	--	--	--	--
dusenburyi Beck	--	--	--	--	--	--	--	--	--	--
cf. *D. jacksonensis* (Cushman and Applin)	--	--	--	F	--	--	--	--	--	--
Dorothia principensis Cushman and Bermudez	--	--	?	--	--	--	--	--	--	--
Ellipsonodosaria cf. *E. cocoaensis* (Cushman)	--	R	--	--	--	--	--	--	--	--
Eponides sp	--	--	--	--	--	--	--	--	--	--
duprei ciervoensis Cushman and Simonson	--	--	--	--	--	--	--	--	--	--
umbonatus (Reuss)	--	--	--	--	--	--	F	?	--	--
Globigerina spp	--	--	C	F	R	--	--	--	--	--
Globobulimina pacifica Cushman	--	--	--	--	--	F	--	--	--	--
Guttulina sp	--	--	--	--	--	--	--	--	--	--
problema d'Orbigny	--	--	--	--	--	--	--	--	--	--
Gyroidina condoni (Cushman and Schenck)	?	--	--	C	--	--	--	?	--	--
orbicularis planata Cushman	--	--	R	--	R	--	--	R	C	R
Karreriella cf. *K. contorta* Beck	--	--	--	--	--	--	--	--	--	--
cf. *K. elongata* Mallory	--	R	--	--	--	--	--	--	--	--
washingtonensis Rau	--	--	--	--	--	--	--	--	--	--
Lagena sp	--	R	--	--	--	--	--	--	--	--
Listerella communis (d'Orbigny)	--	--	--	--	--	--	--	--	--	--
Marginulina subbullata Hantken	--	R	--	--	--	--	--	--	--	--
Nodosaria cf. *N. arundinea* Schwager	--	--	R	C	--	--	R	--	F	R
grandis Reuss	--	--	--	--	--	--	--	--	--	--
Planularia sp	--	R	--	--	?	--	?	--	--	--
cf. *P. markleyana* Church	--	--	--	--	--	--	--	--	--	--
Plectofrondicularia billmani Rau	--	--	--	--	--	--	--	--	--	--
cf. *P. jenkinsi* Church	--	--	--	--	--	--	--	--	--	--
packardi Cushman and Schenck	--	--	--	--	--	--	--	--	--	--
packardi multilineata Cushman and Simonson	--	--	--	--	--	--	--	--	--	--
searsi Cushman, R. E. and Stewart, K. C.	--	C	F	--	--	--	--	?	?	--
cf. *P. searsi* Cushman, R. E. and Stewart, K. C.	--	--	--	--	--	--	--	--	--	--
cf. *P. vaughni* Cushman	--	--	--	--	--	--	F	--	--	--

B, Grays River Area, Washington

as noted. C, common; F, few; R, rare; ?, identification questionable]

F–16 4011	F–17 4195	F–18 S-436	F–19 S-438	F–20[1] 3846	F–21 4192	F–22 4256	F–23 S-417	F–24 S-412	F–25 S-413	F–26 S-411	F–27 S-435	F–28 3913	F–29 4030	F–30 4027
--	--	--	F	--	--	--	--	--	--	C	--	--	--	--
--	--	--	C	--	--	--	--	--	--	--	--	--	--	--
--	--	--	?	--	--	R	R	--	--	--	--	--	--	--
--	--	R	--	--	R	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	C	--	--	--	--	--	--
--	--	--	--	--	--	F	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	F	--	--	C	--	--	--	--	--	--	--	--	--
--	--	--	--	--	?	--	--	--	--	--	--	--	--	--
--	?	--	F	--	R	--	C	C	--	--	F	F	--	--
--	--	--	--	--	--	--	R	--	--	--	--	--	--	--
--	C	--	?	--	--	--	--	--	--	F	--	--	--	--
--	--	?	--	--	--	--	--	--	--	C	--	--	--	?
--	--	R	--	--	C	R	--	C	F	R	--	--	--	R
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	F
--	--	--	--	--	--	--	--	R	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	R
--	--	--	--	C	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
F	F	--	F	F	F	F	--	--	--	F	--	F	--	--
--	--	--	--	--	--	--	--	--	--	--	R	F	C	C
--	F	R	F	--	--	--	F	--	F	--	F	C	--	--
--	--	--	?	--	--	--	--	--	--	--	--	F	--	--
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
R	--	--	--	--	--	--	--	--	--	--	F	--	--	--
--	--	F	--	--	--	--	--	R	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	R	--	--	R	--	--	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	R	R
--	--	--	--	--	--	--	F	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
R	R	--	--	--	F	R	--	--	R	--	C	R	--	--
--	--	--	?	R	--	--	--	--	--	--	--	R	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	?	F	F	F	--	--	--	--	--
F	C	--	R	--	--	F	--	?	--	F	R	C	C	--
--	--	--	--	--	--	--	--	--	--	--	R	--	--	--
--	R	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	?	--	--
--	--	--	R	--	--	R	R	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	F	F	--	--	--	--	--	--	--	--	--	--	--
?	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	R	--	--	--
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	R	--	--	--	--	--
--	--	--	?	--	--	--	--	--	--	--	?	?	F	?
--	--	--	?	--	--	--	--	?	--	C	F	F	?	F
--	?	--	--	C	F	--	?	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 5.—*Foraminifera from unit*

[Identifications by W. W. Rau, Fossil localities shown in fig. 4, except

Fossil localities	F–6	F–7	F–8	F–9	F–10	F–11	F–12	F–13	F–14	F–15
Washington Div. Mines and Geology Lab. No.	S-341	S-428	4024	S-430	4020	4021	4019	4243	4014	4251
Pseudoglandulina conica (Neugeboren)	--	--	--	--	--	--	--	--	--	--
inflata (Bornemann)	--	--	--	--	--	--	--	--	--	--
Pullenia bulloides (d'Orbigny)	--	--	--	--	--	--	--	--	--	--
Quinqueloculina minuta Beck	--	R	--	--	--	--	--	--	?	?
Robulus spp	F	C	R	R	F	R	C	R	F	R
sp. (compressed, many chambers)	--	--	--	--	--	--	--	--	--	--
cf. R. *pseudovortex* Cole	--	--	--	--	R	--	--	--	--	--
welchi Church	?	--	R	--	--	--	--	--	--	--
Siphonodosaria frizzelli Rau	--	--	--	--	--	--	--	--	--	--
Spiroloculina cf. *S. wilcoxensis* Cushman and Garrett	--	--	--	C	--	--	--	--	?	--
Spiroplectammina cf. *S. warrani* (Cushman and Ellison)	--	R	--	--	--	--	--	--	--	--
Uvigerina sp	--	--	--	--	--	--	--	--	--	--
atwilli Cushman and Simonson	--	--	--	--	--	--	--	--	C	F
cocoaensis Cushman	--	--	--	--	--	--	--	--	--	--
garzaensis Cushman and Siegfus	--	--	--	?	F	--	--	C	--	--
cf. *U. yazooensis* Cushman	--	--	--	--	--	--	F	--	--	--
Valvulineria cf. *V. jacksonensis welcomensis* Mallory	--	F	R	?	F	--	--	--	--	--
tumeyensis Cushman and Simonson	--	C	--	?	--	--	--	F	--	--
willapaensis Rau	--	--	--	--	--	--	--	--	--	--
Virgulina sp	--	--	--	--	--	--	--	--	--	--
Vulvulina curta Cushman and Siegfus	--	--	--	--	--	--	R	--	--	--
cf. *V. mississippiensis* (Cushman)	--	--	--	--	--	--	--	--	--	--

[1] SE¼NE¼ sec. 30, T. 11 N., R. 6 W., Skamokawa quad.; Narizian Age.

sive rocks of the northern third of the quadrangle (see p. 29) show a trend (dashed line in figure 12) from the more basic tholeiitic basalt of the Crescent to the andesitic basalt of unit B in the upper Grays River drainage area.

AGE AND CORRELATION

Foraminifera from unit B (table 5) represent the *Bulimina* cf. *B. jacksonensis*, *Uvigerina* cf. *U. yazooensis*, and *Plectofrondicularia* cf. *P. jenkinsi-Bulimina schencki* zones of Rau (1958), of late Eocene age (Narizian Stage of Mallory, 1959), and possibly the *Sigmomorphina schencki* zone (Rau, 1958; Snavely and others, 1958). Rau (written commun., 1967) refers the latter zone to the lower part of the Refugian Stage of Schenck and Kleinpell (1936) and now tentatively regards it as late Eocene in age.

Megafossils are rare in unit B, but collections that contain mollusks and crustaceans (table 6) were made from basaltic or glauconitic sandstone in the Grays River valley above the subaerial volcanic rocks (locality M–1, fig. 4) and on the Naselle River channel near the west edge of the quadrangle (locality M–2, fig.

B, Grays River Area, Washington—Continued

as noted. C, common; F, few; R, rare; ?, identification questionable]

F–16	F–17	F–18	F–19	F–20[1]	F–21	F–22	F–23	F–24	F–25	F–26	F–27	F–28	F–29	F–30
4011	4195	S-436	S-438	3846	4192	4256	S-417	S-412	S-413	S-411	S-435	3913	4030	4027
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	R	F	?	--
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	R	C	F	C	--	R	R	--	--	F	C	F	--	R
--	--	--	--	--	C	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	R	--	R	R	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	R	--	--	--
--	R	--	--	--	C	--	R	--	--	--	--	--	--	--
--	R	--	--	--	--	--	--	--	--	--	--	--	--	--
F	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	?	C	F	--	--	--	--
--	--	--	--	--	--	--	--	--	--	?	--	--	--	--
F	C	C	R	--	--	--	--	--	--	F	R	--	R	F
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	F	--	C	R	--	F	R	R	--	--	--	--	--	--
--	--	F	--	--	C	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	?	--	--	--	--	--	--
--	--	--	--	--	--	--	--	F	--	R	--	F	--	F
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	F	--	--	--	--

4). Gastropods from locality M–1 are distinctive species restricted to the Cowlitz Formation (W. O. Addicott, written commun., 1965) The Cowlitz fauna is correlated with the fauna of the late Eocene "Tejon Stage" (Clark and Vokes, 1936) of the the Pacific coast.

TABLE 6.—*Megafossils from unit B, Grays River area, Washington*

[Identifications by W. O. Addicott. Fossil localities shown in fig. 4. X, present as identified]

Locality (fig. 4) USGS Cenozoic locality	M–1 M2562	M–2 M2785
Pelecypods:		
Acila sp	X	----
Delectopecten sp	----	X
Pitar sp	----	X
Gastropods:		
Fulgurofusus washingtonianus (Weaver)	X	----
Siphonalia sopenahensis (Weaver)	X	----
trochid	X	----
Crustaceans:		
Raninoides sp	----	X
Zanthopsis vulgaris Rathbun	----	X

The massive basalt of the Grays River valley is lithologically similar to basalt of the Goble Volcanic Series (upper Eocene) of Wilkinson, Lowry, and Baldwin (1946), which is exposed along the Columbia River south of Kelso, Wash. Unit B is at least partially equivalent to the Goble Volcanic Series and the associated sedimentary strata of the Cowlitz Formation. The McIntosh, Northcraft, and Skookumchuck Formations of the Centralia-Chehalis district (Snavely and others, 1958), considered as a group, are approximately correlative with most of unit B. The foraminiferal data (fig. 4) suggest that the uppermost part of unit B includes strata of Refugian Age that may be correlative with the lower part of the Lincoln Creek Formation as mapped elsewhere in southwest Washington. Sedimentary rocks of late Eocene age mapped by Rau (1966, 1967) in the southern part of the Olympic Peninsula are equivalent to at least part of unit B. The Nestucca Formation (Snavely and Vokes, 1949) and the associated volcanic rocks in the Oregon Coast Ranges are also approximately correlative with unit B.

PALEOGEOLOGIC SETTING

According to a paleogeographic summary by Snavely and Wagner (1963, fig. 9), the upper Eocene rocks of western Washington and Oregon accumulated in a north-south-trending eugeosynclinal trough with scattered volcanic centers that produced local basaltic islands. In southern Washington, the eastern margin of the basin was probably about 50 miles inland from the present coast.

The predominance of siltstone among the sedimentary rocks is consistent with the offshore marine setting indicated by Snavely and Wagner (1963) for the Grays River area. Foraminifera from siltstones throughout unit B are typical of offshore, open-sea conditions (W. W. Rau, written commun., 1966). Water depths of 1,000 to 5,000 feet are suggested by Foraminifera from unit B rocks of the Naselle valley area; Foraminifera from siltstones overlying the subaerial volcanic rocks in the Grays River valley suggest water depths of 500 to 2,500 feet.

The great thickness of unit B volcanic rocks and the abundance of related intrusive rocks (see Intrusive Rocks, p. 29) indicate that the Grays River area was a local center of late Eocene basaltic volcanism. In the central and western part of the area, the volcanic rocks are entirely of submarine origin, indicated by the occurrence of pillow basalt, flow breccia, and aquagene tuff intercalated with marine sedimentary rocks. However, a large volcanic pile was built above sea level near the eastern edge of the quadrangle. Eventual submergence of the subaerial volcanic mass and its burial by marine sediments are recorded by the friable massive sandstone overlying the subaerial volcanic rocks and by the offshore marine siltstone up into which the sandstone grades.

Although there are local occurrences of basaltic sandstones containing clasts of unit B basalt, most unit B sandstones contain little or no detritus obviously derived from local sources. The sandstone mineralogy suggests derivation from plutonic and metamorphic source rocks similar to the pre-Tertiary crystalline rocks of north-central and northeastern Washington. The abundant glass shards in the siltstones imply contemporaneous explosive volcanism, probably either within the depositional basin or just east of it in the area now underlain by the Cascade Range of Oregon and southern Washington.

Except for the thick massive sandstone, which was mapped in the Grays River valley and which may be a shallow-water transgressive unit deposited as the subaerial volcanic mass was submerged, unit B sandstones are scattered among offshore marine siltstone and volcanic rocks and apparently were deposited in deep water. The predominant sedimentary structures, parallel lamination with some small-scale crossbedding and load structures, are similar to structures in the upper parts of turbidites (Bouma, 1962, p. 49), and because they occur with Foraminifera typical of offshore open-sea conditions, they suggest that the sandstones may represent the distal parts of turbidity current deposits (Walker, 1967).

INTRUSIVE ROCKS

Basaltic intrusives are abundant throughout the quadrangle. However, all intrusive rocks in the southern two-thirds of the quadrangle, as well as the large mass at the west edge (secs. 14 and 23, T. 11 N., R. 9 W.), are related in origin to the flows exposed along the Columbia River, and are described in the section "Basalt Flows and Intrusive Rocks" in this report. The intrusive rocks, described here, in the remainder of the quadrangle range from basalt dikes a few feet wide to relatively large gabbro intrusives.

LITHOLOGY

Many of the small intrusives in the northern third of the quadrangle are porphyritic basalt that closely resembles the porphyritic basalt flows of unit B, and they are undoubtedly shallow intrusives related in origin to the unit B volcanic rocks.

The larger instrusives are diabases to medium-grained augite gabbros that range in texture from intersertal to subophitic; some are porphyritic. In a typical gabbro, twinned and zoned plagioclase, which ranges from labradorite to sodic bytownite (An_{50-75}), occurs as phenocrysts and as subophitic intergrowths with augite (N_y approximately 1.70; 2*V* typically 46°–49°). Olivine is generally completely altered to clay minerals; however, a small amount is preserved in places (Fo_{80} in one occurrence).

Scattered subhedral to skeletal crystals of magnetite or ilmenite occur, and patches of chloritic or montmorillonitic clay minerals fill some interstices.

Some of the intrusive rocks have been albitized. In a typical example (table 7, column 49), plagioclase has been altered to oligoclase and thomsonite, a calcic zeolite. A few unaltered cores in large plagioclase crystals are of labradoritic composition.

Columns 45 to 48 of table 7 represent unalbitized rocks or rocks in which only incipient alteration has occurred (columns 46 and 47 table 20). They contain small amounts of normative quartz and orthoclase, and the normative plagioclase is An_{56-63}. Such rocks approximate Nockolds' average tholeiitic basalt (Nockolds, 1954, table 7), and they fall close to the Crescent–unit B basalt trend in figure 12.

Columns 49 and 50 (table 7) are analyses of albitized rocks probably modified by addition of soda. Their original composition may have been similar to that of the rocks of columns 45 to 48. Because of their usually high soda contents, they fall well above the Crescent–unit B basalt trend shown in figure 12.

AGE AND GEOLOGIC RELATIONS

A late Eocene age is inferred for the intrusive rocks because (1) the smaller intrusives are petrographically similar to the flows of unit B; (2) the intrusive rocks and the volcanic rocks of unit B are closely associated geographically; (3) intrusive rocks extensively intrude the Crescent Formation and units A and B, but are not known to intrude strata younger than unit B; (4) the unaltered intrusive rocks lie close to the Crescent–unit B basalt trend (fig. 12).

EOCENE(?) TO MIOCENE SERIES

LINCOLN CREEK FORMATION

Marine tuffaceous siltstone, with subordinate basaltic and glauconitic sandstone, overlies unit B and is referred to the Lincoln Creek Formation (Beikman and others, 1967). The formation

TABLE 7.—*Chemical analyses and normative compositions, in weight percent, of Eocene intrusive rocks*

[Analyses recalculated to water-free basis. Analytical methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith. Location of samples shown in fig. 4]

	45	46	47	48	49	50
Chemical analyses						
SiO_2	49.9	46.2	47.1	49.1	48.7	48.0
Al_2O_3	16.0	15.1	15.1	16.8	16.1	14.0
Fe_2O_3	3.0	6.1	6.1	5.3	3.3	3.4
FeO	8.9	8.2	8.1	5.7	8.9	10.6
MgO	4.6	6.1	6.0	4.7	5.3	5.8
CaO	10.7	10.4	9.8	12.1	9.0	9.5
Na_2O	2.9	2.6	2.6	2.4	3.9	3.1
K_2O	.61	.57	.56	.17	.91	.67
TiO_2	3.1	4.0	3.9	3.1	3.1	4.0
P_2O_5	.39	.50	.53	.40	.46	.57
MnO	.16	.18	.17	.13	.17	.21
CO_2	----	.10	.05	.08	.16	.08
H_2O-	.68	1.8	1.9	3.0	.59	.79
H_2O+	.91	2.2	1.5	1.0	3.7	1.9
Norms						
Q	2.9	1.7	3.4	7.2	----	----
Or	3.6	3.4	3.3	1.0	5.4	3.9
Ab	24.1	22.1	22.0	20.3	32.7	26.0
An	29.0	27.9	27.8	34.5	23.9	22.5
Wo	9.0	8.3	7.1	9.3	7.0	8.5
En	11.4	15.1	15.0	11.7	6.4	14.4
Fs	9.1	3.9	3.8	1.2	4.2	10.5
Fo	----	----	----	----	4.8	.1
Fa	----	----	----	----	3.5	.1
Mt	4.3	8.8	8.9	7.7	4.8	4.9
Il	5.8	7.5	7.3	5.9	6.0	7.6
Ap	.9	1.2	1.3	.9	1.1	1.4
Cc	----	.2	.1	.2	.4	.2
Normative plagioclase	An_{55}	An_{56}	An_{56}	An_{63}	An_{42}	An_{46}

45. Porphyritic basalt dike in NW¼NW¼ sec. 35, T. 12 N., R. 8 W. Field No. WGR-63-415; USGS Lab. No. 162227.
46. Porphyritic basalt with partially altered plagioclase, SW¼NW¼ sec. 3, T. 11 N., R. 7 W. Field No. WoGR64-592; USGS Lab. No. 164290.
47. Gabbro (from same intrusive as no. 46), SE¼NW¼ sec. 3, T. 11 N., R. 7 W. Field No. WoGR64-593; USGS Lab. No. 164291.
48. Diabase intrusive from SE¼SE¼ sec. 8, T. 11 N., R. 8 W. Field No. WoGR64-494; USGS Lab. No. 164285.
49. Porphyritic basalt with plagioclase altered to oligoclase and thomsonite, NE¼NE¼ sec. 2, T. 11 N., R. 9 W. Field No. WoGR64-476; USGS Lab. No. 164282.
50. Basalt with partially albitized plagioclase, NW¼NW¼ sec. 33, T. 12 N., R. 7 W. Field No. WoGR64-714; USGS Lab. No. 164295.

crops out extensively in the southeastern part of the Grays River quadrangle but has not been recognized elsewhere in the quadrangle. However, unit B and Lincoln Creek siltstones are lithologically similar, and unit B in this area may include some strata equivalent to the Lincoln Creek Formation.

No obvious angular discordance is recognized between the Lincoln Creek Formation and the older rocks in the central part of the quadrangle, but an unconformity separates the Lincoln Creek from unit B east of the Grays River valley.

Sparsity of structural data due to poor exposures precludes a precise determination of the formation's thickness, which undoubtedly varies because of the unconformity between the Lincoln Creek and the overlying Astoria Formation. The Atlantic Richfield Co.–Weyerhaeuser 1 well, near the mouth of Deep River, penetrated approximately 3,500 feet of strata that correlate with the Lincoln Creek Formation on the basis of Foraminifera.

LITHOLOGY

The Lincoln Creek Formation consists of two units of tuffaceous siltstone, each with a basal zone of basaltic and glauconitic sandstone. A discontinuous line drawn from sec. 24, T. 10 N., R. 8 W., to sec. 2, T. 9 N., R. 7 W., indicates the lowest occurrence known of glauconite or sandstone in the upper part of the formation. Relatively well sorted very fine-grained sandstone interlaminated with tuffaceous siltstone near the east edge of the quadrangle (fig. 4) may be a local facies of the lower part of the formation or possibly a pre-Lincoln Creek unit in fault or unconformable contact with the Lincoln Creek.

SILTSTONE

Lincoln Creek siltstone is commonly massive or indistinctly bedded, although it is distinctly bedded locally. In general, bedding is less well developed than in unit B siltstones. The rock is well indurated in the lower part of the formation but becomes less well indurated upward. Concretions are common. In fresh outcrop surfaces the siltstone is gray, but in most exposures it is weathered to soft yellow clay. The siltstone contains scattered clasts of quartz and feldspar, basaltic fragments partly altered to glauconite, and glass shards altered to heulandite in a matrix of montmorillonitic clay (fig. 13). Foraminifera are locally abundant.

LOWER BASALTIC AND GLAUCONITIC SANDSTONE

Basaltic sandstone occurs in the lower part of the Lincoln Creek Formation, and the contact with unit B is at its base. It is thickest, about 800 feet, in the east-central part of the quadrangle near Fossil and Klints Creeks, where it contains interbedded siltstone. The sandstone is medium light gray to olive gray or dark greenish gray, massive, and very fine to fine grained. In the easternmost outcrops, where large clasts are coarsest and most abundant, it contains rounded grains of basalt and glauconite up to half a centimeter in diameter. Carbonized wood fragments occur locally. Molluscan fossils are abundant, and subspherical concretions up to several inches in diameter commonly contain crab re-

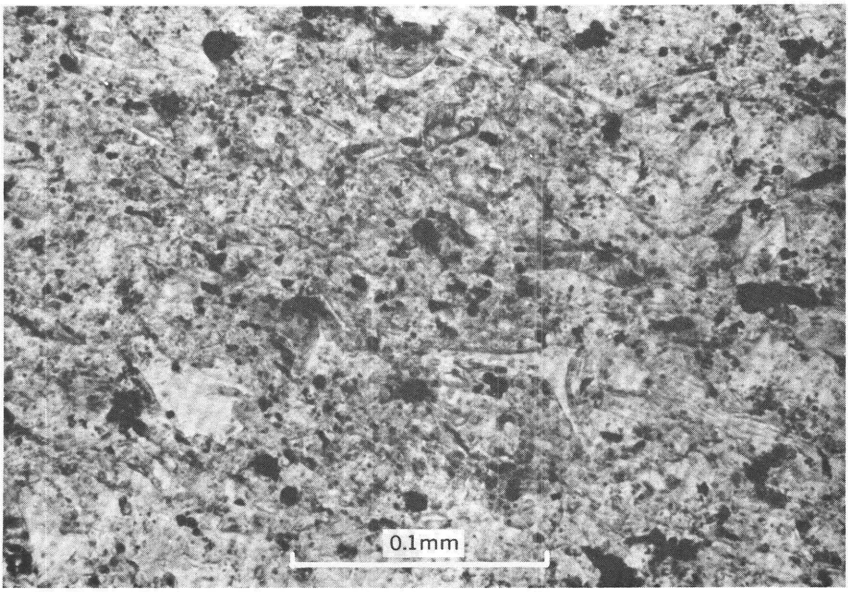

FIGURE 13.—Photomicrograph of Lincoln Creek tuffaceous siltstone. Quartz, feldspar, glass shards, and lithic fragments in montmorillonitic matrix. Black spots are iron sulfide nodules and carbonaceous fragments. Plane-polarized light.

mains. West of the Grays River valley, the sandstone is much thinner, the sandstone-siltstone ratio is lower, and the largest grains are much smaller.

The average composition of the lower basaltic and glauconitic sandstone of the Lincoln Creek Formation is shown below. The data are based on seven thin-section point counts supplemented by counts on stained grain mounts.

	Volume percent (avg)
Monocrystalline quartz	9
Polycrystalline quartz	2
Potassium feldspar	4
Plagioclase	12
Mica and chlorite	4
Volcanic rocks	14
Volcanic(?) rocks	9
Matrix	37
Glauconite	7
Other	2
	100

The lower sandstone is volcanic wacke consisting predominantly of grains of quartz, feldspar, basalt, and glauconite in a matrix of clay minerals, silt, and some calcite (fig. 14). The clasts are mainly angular silt to fine-sand size grains, but rounded volcanic fragments and glauconite grains through the sand and granule sizes occur in places. As a group, the lower sandstones are richer in plagioclase relative to quartz and potassium feldspar than the other Lincoln Creek sandstone units in the map area (fig. 15). Basalt fragments, many with trachytic and porphyritic textures similar to those of unit B volcanic rocks, are commonly altered in varying degrees to glauconite. Although some glauconite formed from nonvolcanic detritus such as biotite or from unidentifiable fine-grained source materials, much of the glauconite is an alteration product of volcanic detritus. Accordingly, rocks with much glauconite have few volcanic and probable volcanic clasts. Typically, volcanic fragments, probable volcanic fragments, and glauconite together make up about 30 percent of lower Lincoln Creek sandstone. Matrix material, from about 30 to 45 percent of the sandstone, is detrital silt and clay, calcite, and clay minerals derived from unstable clasts whose boundaries are now unrecognizable.

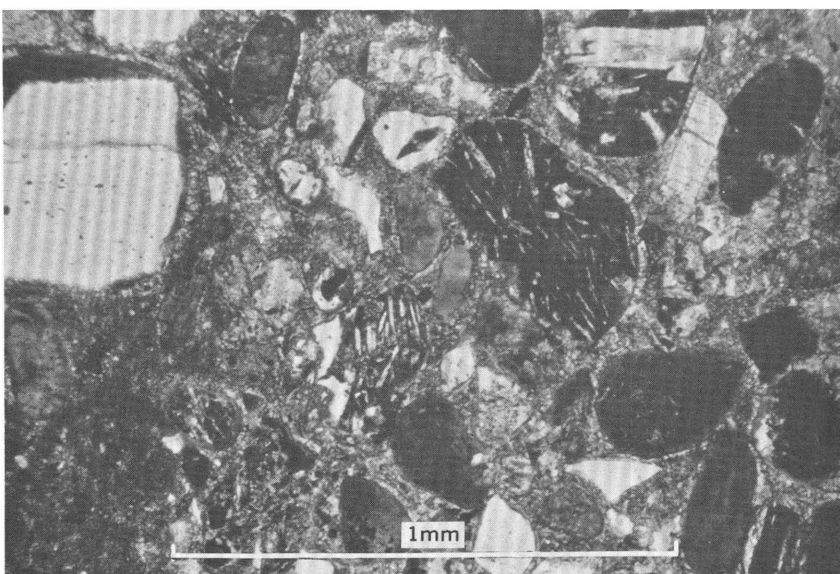

FIGURE 14.—Photomicrograph of lower basaltic sandstone of the Lincoln Creek Formation. Predominantly quartz, feldspar, basaltic fragments, and glauconite in a calcareous matrix. Plane-polarized light.

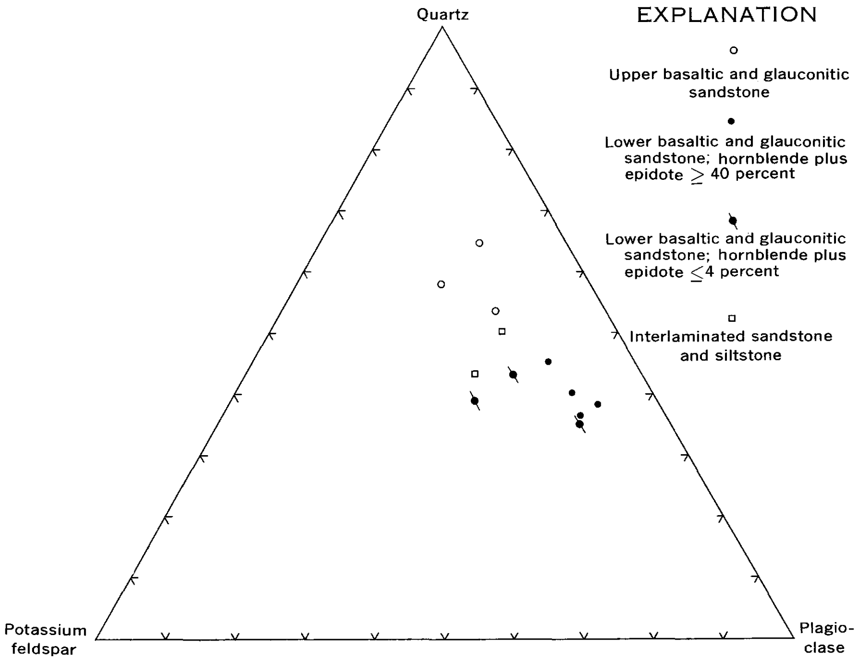

FIGURE 15.—Relative proportions of quartz, potassium feldspar, and plagioclase in Lincoln Creek Formation sandstones.

Heavy minerals from 11 samples from the Grays River quadrangle and from the Skamokawa quadrangle in the headwaters of Fossil Creek were examined. The lower Lincoln Creek sandstones, like the unit B sandstones, can be separated into two distinct groups on the basis of heavy minerals. Heavy minerals from three rocks, two of them from the westernmost outcrops west of Hull Creek, contain 0 to 4 percent hornblende plus epidote and consist mainly of garnet, zircon, sphene, and apatite with small amounts of rutile and tourmaline. The remaining samples, all from east of Hull Creek, contain from 40 to 83 percent amphibole plus epidote. Amphibole is predominantly green or blue-green hornblende with subordinate brown hornblende and, in a few samples, a small amount of a distinctive red oxyhornblende. Zircon, garnet, sphene, and apatite are common in the hornblende-epidote-rich rocks, and tourmaline, rutile, staurolite, and clinopyroxene occur in small quantities. Data are insufficient to show any clear relation between variation in light- and heavy-mineral compositions (fig. 15).

Upper Basaltic and Glauconitic Sandstone

In the upper part of the formation, glauconitic, basaltic, and tuffaceous sandstone is abundant, although subordinate to siltstone. Light-colored tuff beds occur locally. Glauconitic beds are common, some being more than 10 feet thick and in many places consisting of more than 50 percent glauconite.

The upper sandstones are intensively weathered and consist largely of an oxidized paste. Angular quartz and feldspar of silt to very fine sand size constitute about 20 to 25 percent of the rock, and the few other identifiable grains include glauconite, volcanic clasts, and mica. Grain-mount counts of three specimens suggest that the upper basaltic sandstones contain less plagioclase relative to quartz and potassium feldspar than do the lower Lincoln Creek basaltic sandstones (fig. 15).

Green or blue-green amphibole and epidote together constitute 32 to 74 percent of nonopaque heavy minerals counted in seven samples. Zircon, ranging from 1 to 52 percent, is predominant among the remaining heavy minerals. Garnet, sphene, tourmaline, apatite, staurolite, and rutile each generally constitute less than 10 percent of any sample, and monazite, a red oxyhornblende, and clinopyroxene are extremely rare.

East of Jim Crow Creek in the SW¼ sec. 3, T. 9 N., R. 7 W., the small knoll which is nearly enclosed by the 600-foot topographic contour line on the topographic map is underlain by very fine to fine-grained volcanic wacke with a small amount of lapilli tuff. The tuff consists of granules of amygdaloidal vitrophyre and microporphyritic basalt in a sandstone matrix. About 3,000 feet to the east on the small hill in the SE¼ SE¼ sec. 3, T. 9 N., R. 7 W., a breccia dike intrudes tuffaceous sandy siltstone overlain by at least 10 feet of glauconitic sandstone. The dike, which cannot be traced to the top of the outcrop, consists of granules of the same amygdaloidal vitrophyre and microporphyritic basalt as occur in the tuff in a detrital groundmass of very fine to fine-grained sandstone. The vitrophyre granules are angular; plagioclase crystals and sharp projections of volcanic glass extend unbroken from the granules into the enclosing sandstone matrix.

Interlaminated Sandstone and Siltstone

Siltstone with some interlaminated sandstone is exposed in the headwaters of Klints Creek and in roadcuts at the east edge of the quadrangle (fig. 4). The same sequence is also exposed in the valley of Eggman Creek just east of the quadrangle.

The siltstone, which is tuffaceous and montmorillonitic, is relatively soft and contains some mica and abundant finely comminuted carbonaceous debris. The sandstone is relatively well sorted and very fine to fine grained with well-developed lamination and small-scale crossbedding. Mica and carbonaceous debris are abundant on sandstone bedding surfaces, and a few thin coaly laminae occur locally. Round limestone cobbles that may be reworked concretions occur in a 2- to 3-foot-thick lens of sandy conglomerate in Klints Creek. The conglomerate contains poorly preserved mollusks (M–15, table 9); mud pecten shells occur locally on sandstone bedding surfaces.

Modal analyses of two sandstone samples (shown below) from interlaminated sandstone and siltstone indicate that they contain less volcanic detritus than other Lincoln Creek sandstones and less plagioclase relative to quartz and potash feldspar than the nearby lower Lincoln Creek basaltic sandstone (fig. 15). The matrix is clay minerals and calcite.

	Volume percent	*Volume percent*
Monocrystalline quartz	17	13.5
Polycrystalline quartz	4.5	7.5
Potassium feldspar	7	11.5
Plagioclase	14	15.5
Mica and chlorite	7	2.5
Metamorphic rocks	1	1.5
Volcanic rocks	3.5	10.5
Indeterminate fine-grained clasts	6	6
Matrix	40	31
Other	0	.5
	100	100

Predominant nonopaque heavy minerals in the sandstone are zircon, garnet, sphene, and apatite. Minor constituents include tourmaline, staurolite, rutile, epidote, and rare hornblende.

Poor exposure obscures the relations of the interlaminated sandstone and siltstone to the lower part of the Lincoln Creek Formation, which crops out nearby. The interlaminated sandstone and siltstone differ from the nearby Lincoln Creek strata in both mineralogy and fabric but resemble the very fine-grained sandstone and interlaminated siltstone in unit B. In figure 4 the unit is shown as a local facies of the lower part of the Lincoln Creek. Alternatively, it may be part of unit B, either in fault contact with, or unconformably overlain by, the Lincoln Creek.

AGE AND CORRELATION

Foraminifera (table 8) from the lower basaltic sandstone of the Lincoln Creek Formation (F–31 to F–36) represent the *Sigmomorphina schencki* zone of Snavely and others (1958) and *Cassidulina galvinensis* zone of Rau (1966) of latest Eocene(?) and Oligocene age (Refugian Stage of Schenck and Kleinpell, 1936). Foraminifera from the remainder of the formation (F–37 to F–47) represent the *Pseudoglandulina* aff. *P. inflata* zone (Rau, 1958) of Oligocene age (Zemorrian Stage of Kleinpell, 1938). Foraminifera (see fig. 4) suggest that the uppermost part of unit B (of early Refugian Age) in the Grays River area may

TABLE 8.—*Foraminifera from Lincoln Creek*

[Identifications by W. W. Rau, Fossil localities shown in fig. 4, except

Fossil localities	F–31	F–32
Washington Div. Mines and Geology Lab. No	S-410	S-408
Allomorphina macrostoma Karrer	C	--
Anomalina californiensis Cushman and Hobson	--	--
Bolivina sp	--	--
marginata adelaidana Cushman and Kleinpell	--	--
Buccella mansfieldi oregonensis (Cushman, R. E. and Stewart, K. C.)	--	--
Bulimina alligata Cushman and Laiming	--	--
pupoides d'Orbigny	--	F
Buliminella subfusiformis Cushman	--	--
Cassidulina crassipunctata Cushman and Hobson	--	--
galvinensis Cushman and Frizzell	?	--
Cassidulinoides sp	--	--
Cibicides elmaensis Rau	F	--
aff. *C. perlucida* Nuttall	--	--
Cornuspira byramensis Cushman	--	--
Dentalina spp	R	C
sp. C of Rau, 1948	--	--
quadrulata Cushman and Laiming	--	--
Ellipsonodosaria cf. *E. cocoaensis* (Cushman)	--	--
Elphidium cf. *E. minutum* Cushman	--	--
Entosolenia sp.	--	--
Eponides yeguaensis Weinzierl and Applin	--	--
Gaudryina alazanensis Cushman	--	--
Globigerina spp	--	F
Guttulina sp	--	R
hantkeni Cushman and Ozawa	--	--
Gyroidina orbicularis planata Cushman	F	C
Karreriella washingtonensis Rau	--	--
Lagena semistriata Williamson	--	--
Nodosaria cf. *N. arundinea* Schwager	--	--
cf. *N. grandis* Reuss	--	R
Nonion cf. *N. incisum* (Cushman)	--	--
pompilloides (Fichtel and Moll)	--	--
Plectofrondicularia packardi multilineata Cushman and Simonson	R	?
searsi Cushman, R. E. and Stewart, K. C	--	--
cf. *P. vaughni* Cushman	--	R
Pseudoglandulina inflata (Bornemann)	--	--
Pyrgo lupheri Rau	--	?
Quinqueloculina sp	--	--
imperialis Hanna and Hanna	--	--
weaveri Rau	--	--
Robulus spp	--	--
cf. *R. limbosus hockleyensis* (Cushman and Applin)	--	--
Sigmomorphina schencki Cushman and Ozawa	R	C
Siphonodosaria frizzelli Rau	--	--
Spiroloculina texana Cushman and Ellisor	--	--
Uvigerina garzaensis Cushman and Siegfus	--	R
Valvulineria willapaensis Rau	--	--
Virgulina sp	--	--

[1] SW¼NE¼, sec. 1, T. 9 N., R. 7 W., Skamokawa quad.; Refugian Stage.

represent strata which are included in the Lincoln Creek Formation in other areas of southwest Washington.

Mollusks (table 9) from the lower basaltic sandstone are referable to the Oligocene "Lincoln Stage" of Weaver and others (1944). Faunal groups corresponding to the *Molopophorus gabbi* (M–3 to M–8) and *Turritella porterensis* (M–9 to M–14) zones of Durham (1944) are recognized. The same strata contain Foraminifera of Refugian Age.

Megafossils occurring just below the base of the upper basaltic and glauconitic sandstone and within the upper part of the Lincoln Creek Formation are referable to the *Echinophoria rex*

Formation, Grays River area, Washington

as noted. C, common; F, few; R, rare; ?, identification questionable]

F–33 4185	F–34[1] 4260	F–35 S-407	F–36 4187	F–37 3901	F–38 3899	F–39 3897	F–40 3903	F–41 3898	F–42 3906	F–43 3905	F–44 4206	F–45 3904	F–46 4203	F–47 4350
--	--	--	--	--	--	--	--	--	--	--	--	--	F	--
--	--	F	--	?	--	R	--	--	--	--	--	?	--	--
--	--	--	--	--	--	R	--	--	--	--	--	R	--	--
--	--	--	--	F	--	--	C	--	--	--	F	--	--	--
--	--	--	--	F	--	--	--	--	--	--	--	--	--	R
--	--	--	--	--	R	--	--	--	--	--	R	--	--	--
--	--	F	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	F	--	--	--	--	F	--	--	C
--	--	--	--	F	F	C	C	F	--	?	C	C	R	C
F	--	F	--	--	?	--	--	--	--	--	--	--	--	--
--	--	R	--	--	--	--	--	--	?	--	--	R	--	R
R	--	F	--	--	--	R	--	--	--	--	--	R	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	F
--	--	--	--	--	--	--	--	--	?	--	--	--	--	--
--	--	--	R	--	--	--	R	F	--	--	--	--	--	R
--	--	--	--	--	--	R	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	R
--	--	--	--	--	--	--	--	--	--	--	--	F	--	--
--	--	--	--	C	--	--	--	--	--	R	R	--	--	--
--	--	--	--	--	--	F	--	--	--	--	R	R	R	R
R	--	--	--	--	--	--	--	--	--	--	--	--	--	--
R	--	--	--	R	--	--	--	--	--	--	R	F	F	F
--	--	--	--	R	--	--	--	--	--	--	R	--	R	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	R	--	--	--	--	--	--	--	--	--	--	--
C	--	F	C	C	F	R	F	--	R	F	--	C	R	F
--	--	--	--	--	--	--	--	--	R	--	--	--	--	--
--	--	--	--	--	R	--	--	--	--	--	--	--	--	--
--	--	?	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	R	--	--	--	--	--	?	--	--	--	--	--	C
--	--	--	--	--	--	--	--	--	--	--	--	--	?	--
--	--	F	--	--	F	?	F	--	--	--	--	F	--	?
--	--	--	F	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
R	--	F	?	--	--	R	F	--	F	C	C	F	F	F
R	--	--	--	--	R	--	--	--	--	--	--	--	R	--
--	--	--	--	--	--	--	--	R	--	--	--	--	--	--
F	--	F	R	--	--	--	--	--	--	--	--	F	--	--
--	--	R	--	C	F	--	--	--	--	--	--	F	--	--
C	--	C	--	--	F	R	R	R	R	--	R	--	--	F
--	--	F	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	C	--	R	--	--	--	--	--	--	--	--	--
--	--	--	--	--	R	--	--	--	--	--	--	--	--	--
--	--	R	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	R	--	--	--	--	R	--	--	--
--	C	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	R	?	--	--	--	--

TABLE 9.—*Megafossils from Lincoln Creek*

[Identifications by W. O. Addicott. Fossil localities shown in fig. 4, except as noted. X, present as for definite identification; aff, comparable but apparently different form; sp, species not determinable; ?

Fossil localities	M–3	M–4	M–5	M–6	M–7	M–8[1]
U.S.G.S. Cenozoic locality	M2506 M2564	M2499	M2507	M2508	M2518	M2590
Gastropods:						
Acteon sp	---	---	---	X	---	---
Aforia campbelli Durham	---	---	---	---	---	---
cf. *A. clallamensis wardi* (Tegland)	---	---	---	---	---	---
Ampullina? sp	---	---	---	---	---	---
Ancistrolepis clarki forma *teglandae* Durham	---	---	---	---	---	---
Bathybembix washingtoniana (Dall)	---	---	---	---	---	---
Bruclarkia columbiana (Anderson and Martin)	---	---	---	X	---	---
Calyptraea sp	---	---	---	---	---	---
"*Chrysodomus*" *packardi* Weaver	---	---	---	---	---	?
"*Echinophoria*"	---	---	---	---	---	---
Exilia lincolnensis Weaver	---	---	---	---	---	---
Liracassis apta (Tegland)	---	---	---	---	---	---
rex (Tegland)	---	---	---	---	---	---
Naticid	---	---	X	---	---	---
Neverita sp	---	---	---	---	---	---
Perse lincolnensis (Van Winkle)	---	---	---	---	---	---
olympicensis quimperensis Durham	---	cf	cf	X	cf	---
Polinices cf. *P. washingtonensis* forma *lincolnensis* (Weaver)	---	---	---	?sp	---	---
Priscofusus chehalisensis (Weaver)	---	---	---	---	---	---
cf. *P. stewarti* (Tegland)	---	---	---	---	---	---
Propebela? sp	---	---	---	---	---	---
Scaphander cf. *S. gordoni* Tegland	---	---	---	---	---	---
Siphonalia washingtonensis (Weaver)	---	---	?sp	X	---	---
Turricula washingtonensis (Weaver)	---	---	---	---	---	---
Turritella diversilineata Merriam	---	---	---	?sp	---	---
aff. *T. hamiltonensis* Clark	---	---	---	---	---	---
Pelecypods:						
Acila (Truncacila) shumardi (Dall)	X	---	sp	sp	---	cf
(Acila) gettysburgensis (Reagan)	---	---	---	---	---	---
cf. *A. nehalemensis* Hanna	---	---	---	X	---	---
Cardid	---	---	---	---	---	---
Cochlodesma bainbridgensis Clark	---	---	---	---	---	---
Crenella porterensis Weaver?	---	---	---	---	---	---
Delectopecten aff. *D. peckhami* (Gabb) Arnold	X	---	---	---	---	---
Katherinella arnoldi (Weaver)	---	---	---	---	---	---
Lucina (Callucina?) dalli (Dickerson)	---	---	---	X	---	---
Lucinid	---	---	X	---	---	---
Lucinoma cf. *L. hannibali* (Clark)	---	---	---	---	---	---
Macoma lorenzoensis arnoldi Tegland	---	---	---	?sp	---	---
twinensis Clark	---	---	---	---	---	---
Macrocallista pittsburgensis (Dall)	---	---	---	X	---	---
Mytilid	---	---	---	---	---	---
Nemocardium lorenzanum (Arnold)	---	?sp	---	---	---	---
Nuculana sp	---	---	---	---	---	---
(Saccella) washingtonensis (Weaver)	sp	---	cf	X	---	---
Periploma bainbridgensis (Clark)	---	---	---	---	---	---
Pitar dalli (Weaver)	---	---	---	sp	---	---
Plagiocardium? lincolnensis (Weaver)	---	X	X	X	---	---
Portlandia chehalisensis (Arnold)	---	---	---	---	---	---
Solemya (Archarax) cf. *S. (A.) dalli* Clark	---	---	---	---	---	---
Solen conradi Dall	---	---	---	---	---	---
cf. *S. lincolnensis* Weaver	---	---	---	X	---	---
Spisula pittsburgensis Clark	cf	---	?sp	X	---	?sp
Tellina kamakawaensis Clark	---	---	---	X	---	---
lincolnensis Weaver	---	---	---	X	---	---
? aff. "*T. obruta* Conrad" of authors	---	---	---	X	---	---
townsendensis Clark	---	---	---	X	---	cf
Tellinid	---	---	X	---	---	---
Thracia condoni Dall	---	---	---	---	---	---
schenki Tegland	---	---	---	---	---	---
Thyasira cf. *T. disjuncta* (Gabb)	---	---	---	---	---	---
Yoldia cf. *Y. chehalisensis* (Arnold)	---	---	---	---	---	---
Cephalopod	---	---	---	---	---	---
Aturia angustata (Conrad)	---	---	---	---	---	---
Scaphopod	---	---	---	---	---	---
Dentalium porterensis Weaver	---	---	---	?sp	---	---
Decapod crustacean	---	---	---	---	---	---
Zanthopsis vulgaris Rathbun	X	---	---	---	---	---
Barnacle	---	---	---	X	---	---
Fish scales	---	---	---	---	---	---

[1] SE¼SW¼ sec. 7, T. 10 N., R. 6 W., Skamokawa quad.

Formation, Grays River area, Washington

identified; ?, doubtful identification; cf, similar form, specimen(s) incomplete or too poorly preserved sp, genus questionably identified]

M–9	M–10	M–11	M–12	M–13	M–14	M–15	M–16	M–17	M–18	M–19	M–20	M–21
M2561	M2501	M2500	M2505	M2565	M2504	M2566	M2502	M2503	M2786	M2784	M2589	M2782
---	---	---	?	---	---	---	---	---	---	---	---	---
---	---	X	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	X	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	?	---	---	---
---	---	---	---	---	---	---	---	---	X	---	---	---
?	---	---	cf	---	---	?sp	---	---	---	---	---	---
---	---	---	X	---	---	---	---	---	---	---	---	---
?	---	---	---	---	---	---	---	---	---	---	---	---
X	---	---	---	---	---	---	---	---	---	---	---	---
---	---	X	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	X	X	---	---
---	---	---	---	---	---	---	X	X	---	---	---	---
X	---	---	X	X	X	---	X	X	---	---	---	X
---	---	---	---	---	---	X	---	---	---	---	---	---
X	X	cf	cf	cf	X	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	X	sp	---	---	---	---	---	---	---	---	---
X	---	X	---	cf	?	---	---	---	---	---	---	---
---	---	---	X	---	---	---	---	---	X	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	X
sp	---	---	---	---	---	---	---	X	---	---	---	---
X	---	---	---	---	---	---	---	---	---	---	---	---
---	---	X	?	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	X	---	---	---	---	X
---	---	---	---	---	---	---	X	X	---	---	---	---
---	sp	cf	X	---	---	sp	---	---	sp	---	---	sp
---	---	---	---	---	---	---	X	X	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	X	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
---	---	---	X	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	sp	---	---	---	---	---	---
X	cf	---	X	X	X	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	?sp	---	sp	X	---	sp	---	---	---
---	---	X	---	cf	---	sp	---	---	---	---	---	---
---	---	---	---	---	---	---	cf	X	---	---	---	---
X	X	sp	?sp	sp	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	X
?	X	---	X	---	cf	---	---	cf	---	---	---	cf
---	---	---	---	---	---	---	---	---	---	---	---	X
sp	X	---	sp	sp	sp	---	---	---	---	---	---	---
---	---	---	cf	---	---	---	X	?	---	---	---	---
cf	cf	cf	sp	X	X	sp	---	sp	---	---	---	---
---	X	---	---	---	---	---	---	---	---	---	---	---
---	---	---	X	X	cf	?sp	---	---	---	---	---	---
---	---	---	---	---	---	---	X	---	sp	---	---	sp
---	---	X	sp	sp	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	?	---	X	---	X	---	---	X	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	X
X	sp	cf	cf	cf	cf	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
---	---	---	---	---	---	---	---	---	---	X	---	sp
---	---	---	---	---	cf	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	X	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
sp	sp	X	---	---	sp	sp	---	---	---	---	---	sp
---	---	---	---	---	---	---	---	X	---	---	---	---
---	---	X	---	---	---	---	---	---	---	---	---	---
X	X	---	---	---	---	---	---	---	---	---	---	---
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(M–16 to M–17) and *Echinophoria apta* (M–18 to M–21) zones (Durham, 1944) of the "Blakeley Stage" of late Oligocene and early Miocene age (Weaver and others, 1944). Foraminifera from this part of the formation represent the Zemorrian *Pseudoglandulina* aff. *P. inflata* zone, which Rau regards as Oligocene.

Stratigraphic relations and age of the interlaminated sandstone and siltstone at the east edge of the quadrangle are not clear. No diagnostic Foraminifera were found. Poorly preserved megafossils (M–15) suggest an age no younger than Oligocene.

PALEOGEOLOGIC SETTING

The Lincoln Creek Formation was deposited in a north-south-trending geosyncline open on the west to the Pacific Ocean and bounded on the east by largely volcanic continental deposits which accumulated in the area of the Cascade Range. Islands and peninsulas of pre-Oligocene rock disrupted the continuity of the marine basin (Snavely and Wagner, 1963, fig. 13; Wagner and Snavely, 1966, p. 42).

Foraminiferal and molluscan paleoecologic data suggest an open-sea, offshore, sublittoral to bathyal environment of deposition. Foraminifera indicate water depths of 300 to 1,000 feet for deposition of the lower part of the formation and 1,000 to 3,000 feet for deposition of the upper part (W. W. Rau, written commun., 1966). Mollusks from the lower sandstone suggest a sublittoral environment with water depths of less than 600 feet, whereas mollusks from the upper part of the formation suggest a somewhat deeper outermost sublittoral or possible upper bathyal environment (W. O. Addicott, written commun., 1965).

The presence of a subaerial mass of pre-Oligocene rock near the east edge of the quadrangle during the earliest stages of Lincoln Creek deposition is indicated by the angular unconformity at the base of the Lincoln Creek Formation near the east edge of the quadrangle and by the abundance in the lower sandstone of volcanic detritus apparently derived from erosion of unit B subaerial volcanic rocks. Absence of a recognizable microfaunal break, the rapid westward thinning of the lower sandstone, and the apparent conformity between the Lincoln Creek Formation and unit B west of Grays River indicate that deposition of unit B and Lincoln Creek strata may have continued uninterrupted a short distance west of the pre-Oligocene subaerial high. The upward change from basaltic sandstone to siltstone implies submergence of the local source of basaltic detritus.

The upper basaltic and glauconitic sandstone may include detritus either eroded from older volcanic rocks within the basin or derived from volcanic debris deposited east of the geosyncline. However, the presence of the breccia dike east of Jim Crow Creek and the nearby outcrops of volcanic wacke and lapilli tuff of similar composition (p. 36) suggests that local submarine volcanism may also have contributed detritus to the upper basaltic and glauconitic sandstone.

In addition to the preponderant volcanic detritus, the basaltic sandstones of the Lincoln Creek Formation contain heavy minerals derived from crystalline rocks; amphibolites or hornblende gneisses probably supplied the abundant green and blue-green hornblende. Such rocks are common in the pre-Tertiary orogenic belt exposed in the northern Cascade Range and in the Klamath Mountains. The abundance of glass shards throughout the formation and the presence of tuff beds in the upper part of the formation record the nearly continuous pyroclastic volcanism that characterized the eastern margin of the geosyncline (Snavely and Wagner, 1963, p. 16).

MIOCENE SERIES

ASTORIA FORMATION

Siltstone and sandstone unconformably overlying the Lincoln Creek Formation are referred to the Astoria Formation. The name "Astoria shales" was originally applied by Condon (Cope, 1880) to fossiliferous sedimentary rocks that were exposed in the vicinity of Astoria, Oreg., but that have since been concealed by urban development. Other geologists working in southwestern Washington (for instance, Pease and Hoover, 1957; Snavely and others, 1958; Wagner, 1967a, b) have used the name Astoria(?) Formation for Miocene strata underlying or interfingering with basalt of Miocene age. The name is used here in a similar sense, with the exception that the Astoria Formation is not known to interfinger with basalt in the Grays River area.

In this report the Astoria Formation is subdivided into three units on the basis of mineral composition and, in part, megascopic differences recognized in the field. Designated I, II, and III in figure 4, the units together are equivalent to the previously mapped Astoria(?) Formation. Unit III coincides with the unnamed unit mapped along the Columbia River bank near Rocky Point and on the ridge between Sisson and Salmon Creeks in the southwestern part of the quadrangle (Wolfe and McKee, 1968).

The maximum thickness of the Astoria Formation is unknown. The Atlantic Richfield Co.–Weyerhaeuser 1 well, near the mouth of Deep River, was drilled through about 2,600 feet of strata considered to be the Astoria Formation on the basis of Foraminifera. This 2,600-foot thickness, plus approximately 800 feet of Unit I strata exposed southwest of the well, plus 1,000 feet or more of Unit III, total approximately 4,500 feet for the thickness of the Astoria Formation in the southwest part of the Grays River quadrangle. The available data suggest that the Astoria Formation is unusually thick in the central part of the quadrangle, but the probability of undetected structural repetition precludes determination of the actual thickness. In the southeastern part of the quadrangle the thickness ranges from less than 500 feet near the eastern edge of the map area to approximately 2,000 feet in the exposures north of Dahlia.

LITHOLOGY

Unit I, Astoria Formation

Unit I, extensively exposed in the valleys of Grays and Deep Rivers, is mainly soft dark-gray argillaceous siltstone to very fine-grained sandstone. Fine-and medium-grained sandstones are rare. In contrast to most of the pre-Astoria sedimentary rocks, unit I contains abundant mica and finely comminuted carbonaceous debris. Glauconite occurs commonly as scattered grains or, rarely, is concentrated in beds. Calcareous concretions and massive siltstone similar in appearance to Lincoln Creek siltstone occur locally. Unit I is sparsely fossiliferous.

Much of unit I shows little or no bedding; excavation of relatively unweathered outcrops reveals that nearly all depositional structure has been destroyed, presumably by burrowing organisms. Discontinuous wispy layers exposed locally by digging are interpreted as remnants of original bedding, and many of the strikes and dips of unit I were measured on them.

Thin sections show that unit I siltstone-sandstone consists of angular to subangular clasts ranging in size from coarse silt to fine sand in a matrix that is approximately 30 to 55 percent of the rock. The matrix contains detrital silt and clay, as well as unstable clasts so altered that original grain boundaries are indistinguishable. Point counts supplemented by stained grain counts give an average composition (table 10) of nearly equal amounts of quartz and feldspar and abundant volcanic detritus. Unit I tends to be less rich that unit II and more rich than unit III in plagioclase relative to quartz plus potash feldspar (fig. 16). In contrast to unit III, unit I generally contains more plagioclase than potash feldspar.

TABLE 10.—*Average compositions, in volume percent, of Astoria Formation sandstones*

	Unit I	Unit II		Unit III
	(9 samples)	Altoona Ridge (6 samples)	North of Eden Valley (4 samples)	(9 samples)
Monocrystalline quartz	15	19	14	20
Polycrystalline quartz	4	4	4	10
Potassium feldspar	7	9	6	16
Plagioclase	10	18	14	10
Mica and chlorite	2	8	5	6
Metamorphic rocks	1	1	--	2
Volcanic rocks	5	7	4	8
Volcanic(?) rocks [1]	7	7	11	5
Matrix	46	20	40	22
Other	4	5	2	2

[1] Volcanic(?) rocks are fine-grained rocks that are probably largely glassy volcanic fragments.

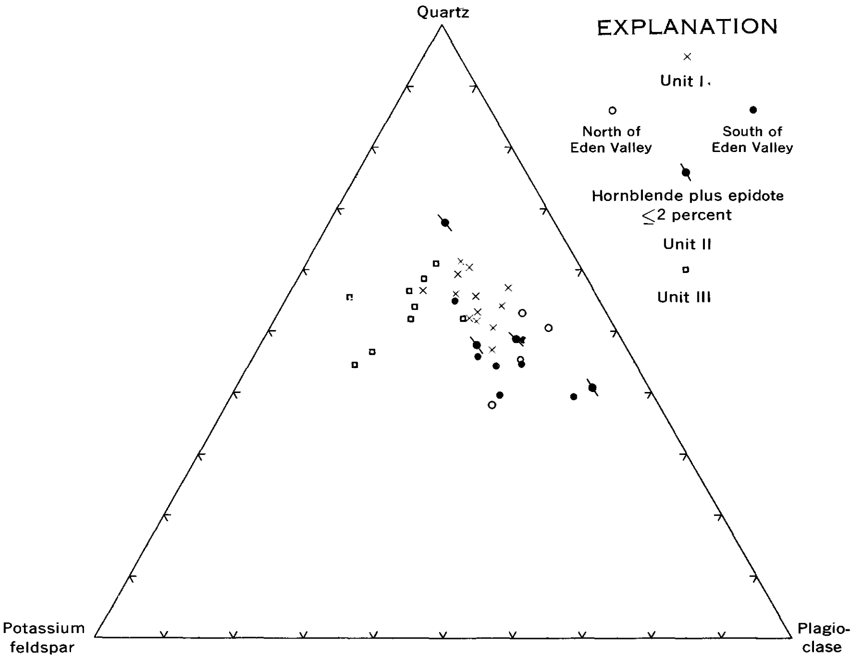

FIGURE 16.—Relative proportions of quartz, potassium feldspar, and plagioclase in the Astoria Formation.

The heavy minerals of unit I consist predominantly of zircon and garnet, with lesser amounts of sphene, tourmaline, apatite, and staurolite, and minor monazite, rutile, and kyanite (table 11). In contrast to unit II, unit I contains little hornblende and epidote (fig. 4).

UNIT II, ASTORIA FORMATION

Unit II, in part a lateral equivalent of unit I, forms a band along the east edge of unit I and includes all of the Astoria For-

TABLE 11.—*Heavy-mineral composition of the Astoria Formation, in percent*

	Unit I (20 samples)	Unit II: Altoona Ridge: Low hornblende-epidote (<10 percent) (9 samples)	Unit II: Altoona Ridge: High hornblende-epidote (>10 percent) (24 samples)	Unit II: North of Eden Valley (6 samples)	Unit II: Unit II Average (39 samples)	Unit III (10 samples)
Hornblende	--	1	35	8	23	--
Epidote	1	1	20	29	17	--
Zircon	30	26	10	9	13	20
Garnet	31	21	13	20	16	38
Sphene	11	17	9	15	12	6
Tourmaline	8	10	4	7	5	9
Apatite	6	12	6	10	8	11
Monazite	3	2	--	--	1	3
Rutile	3	2	1	1	1	2
Staurolite	6	6	2	2	3	7
Kyanite	1	1	--	--	--	1
Other	1	0	--	--	--	2

mation on Altoona Ridge, immediately north of the Columbia River, in the eastern two-thirds of the quadrangle (fig. 4). West of the north-south fault that separates the Astoria and Lincoln Creek Formations, units I and II are megascopically much alike and, at least in the area north of Eden Valley, were first distinguished on the basis of mineralogy. Unit II, however, is sandier, slightly coarser (siltstone to fine-grained sandstone), more distinctly bedded, and more fossiliferous than unit I. West of the fault, near the mouth of Eden Valley, unit II overlies unit I, but farther north unit II is apparently a lateral equivalent of unit I. Relatively clean sandstone in beds as thick as 160 feet is interbedded with typical argillaceous Astoria strata on the ridge north of the Columbia River in the eastern half of the quadrangle, where the Astoria rests unconformably on the Lincoln Creek Formation. The clean sandstone is best exposed in outcrops north of Brookfield and on the ridge above Fink Creek. It is generally very fine to fine grained and is cross-bedded on a large scale. Similar sandstone underlies the unit called basalt of Altoona (see p. 57) between Altoona and Dahlia along the bank of the Columbia River and occurs in a few thin beds south of Eden Valley, on the western part of Altoona Ridge.

Unit II rocks are similar to unit I rocks in containing subequal amounts of quartz and feldspar and abundant volcanic and probable volcanic detritus in a matrix of detrital silt and clay and the decomposition products of altered unstable clasts (table 10). The lower average matrix content (20 percent) of the rocks on the ridge north of the Columbia River reflects the low matrix content (as low as 4 percent) of the well-sorted sandstones interbedded with typically argillaceous Astoria siltstone and sandstone.

On the average, unit II is richer in plagioclase than unit I, and hence total feldspar exceeds quartz (table 10, fig. 16). With the exception of two Altoona Ridge samples of relatively well-sorted sandstone with unusually high quartz values (55 and 68 percent), unit II is typically richer in plagioclase relative to quartz and potash feldspar than units I and III. Feldspar is generally more abundant than quartz in unit II and less abundant than quartz in unit I.

Unit II heavy minerals as a group are distinguished by the abundance of green and blue-green hornblende and epidote (fig. 4, table 11). Apart from hornblende and epidote, unit II heavy minerals are similar in kind and quantity to those of unit I. They consist mainly of zircon, garnet, sphene, and apatite, with minor tourmaline, staurolite, monazite, rutile, and kyanite. Hornblende and epidote are absent to scarce in 9 of 33 samples collected from Altoona Ridge. No systematic relationship between hornblende-epidote abundance and texture, composition, or stratigraphic or geographic position within unit II was discovered.

UNIT III, ASTORIA FORMATION

Unit III overlies unit I near the west edge of the quadrangle, west of Deep River. The unit consists of more than 1,000 feet of bedded siltstone with interbeds of very fine to very coarse grained friable sandstone from half an inch to at least 40 feet thick. The sandstone forms abundant clastic dikes that intrude the surrounding sedimentary rocks. Light-colored tuffaceous beds ranging in thickness from about a sixteenth of an inch to 1 foot occur locally. The unit as a whole is characterized by parallel stratification; crossbedding is rare. Parallel lamination and thin bedding result from alternation of tuff and siltstone beds, or from concentration of carbonaceous detritus in layers within or at the tops of massive sandstone beds. Locally, the sandstone also contains beds of tabular pebbles and cobbles derived from the associated siltstone.

On the ridge south of Salmon Creek, about half a mile west of the quadrangle boundary, a conglomerate of pebbles and cobbles of basalt is exposed in a single outcrop. Sedimentary rocks above and below the conglomerate are similar, except that the overlying siltstone may be more tuffaceous than the underlying siltstone and contains abundant pumiceous granules and pebbles as well as oxidized leaf fragments.

Except for an isolated concentration of mud pectens, no megafossils were found in unit III. Foraminifera are present in the siltstone.

Unit III sandstones contain angular grains through the range of sand sizes and hence are coarser than the grains of units I and II. Unit III sandstones, like those of unit I, typically contain slightly more quartz than feldspar and also contain fairly abundant fragments of volcanic and probable volcanic origin (table 10). Polycrystalline quartz comprises a larger part of the total quartz than in units I and II, probably because of the coarser grain size of unit III. Matrix is less abundant (8 to 25 percent) than unit I matrix and contains no obvious detrital fines. Volcanic clasts grade into the matrix, which may be entirely decomposition products of unstable fragments. Unit III is distinctive because of its low plagioclase content relative to quartz and potash feldspar and its higher ratio of potash feldspar to plagioclase (usually > 1) (fig. 16).

Nonopaque nonmicaceous heavy minerals from the silt to very fine sand fractions are similar to those of unit I. Garnet and zircon predominate; tourmaline, sphene, apatite, and staurolite are present in moderate amounts; monazite, rutile, and kyanite are minor constituents; epidote and hornblende are rare (table 11; fig. 4).

AGE AND CORRELATION

Foraminifera collected from surface exposures and shallow auger holes in units I and II, and in unit III in its more southern outcrop, are referable to the Saucesian Stage (early Miocene) of Kleinpell (1938). No foraminiferal zonation has been recognized in these rocks. However, Foraminifera collected from two localities less than 2 miles west of the Grays River quadrangle, on the ridge between Salmon and Sisson Creeks, suggest that at least part of unit III, in its ridge outcrops, may be younger than the rest of the Astoria in the Grays River area. Foraminifera from just below the basalt sill near the west end of the ridge (F–49, table 12) are referred to the *Baggina washingtonensis* zone, which Rau (1967, p. 24, 25) suggests may represent the late Saucesian, Relizian, and early Luisian Stages (early to middle Miocene) of Kleinpell (1938). Although the evidence is not as conclusive, Foraminifera from siltstone above the same sill just west of the quadrangle (F–60, table 12) may also belong to the *Baggina washingtonensis* zone. On the basis of Foraminifera, most of the Astoria Formation of the Grays River area is correlative with the Nye Mudstone and Astoria Formation of the Newport Embayment, Oregon (Snavely and others, 1964), with at least a lower part of the Clallam Formation of the northern Olympic Peninsula (Rau, 1964), and with a lower part of the Astoria of the Grays Harbor basin.

Molluscan assemblages from the Astoria Formation of the Grays River area (table 13) correlate with the fauna of the Astoria Formation of Oregon (Moore, 1963), which is assigned to the middle Miocene "Temblor Stage" on the basis of faunal correlation with Califonia rocks. In the Newport Embayment of Oregon the Astoria fauna extends down into the upper part of the Nye Mudstone. Hence, the Astoria of the Grays River area is broadly correlative with the upper part of the Nye Mudstone, as well as with the Astoria Formation of the Newport Embayment (W.O. Addicott, written commun., 1966).

PALEOGEOLOGIC SETTING

Previously published summaries of the geologic history of western Washington indicate that by the latter part of early Miocene time the eastern shoreline of the marine basin had shifted westward to the approximate position of the present coastline. Local structural downwarps, however, indented the Miocene coastline. Marine sedimentary rocks of the Astoria Formation of the Grays River area were deposited in such a downwarp, near the mouth of the present Columbia River. Detritus was probably derived largely from northeastern Washington and carried westward by an ancestral Columbia River (Snavely and Wagner, 1963; Wagner and Snavely, 1966).

Foraminifera from unit I suggest an offshore, open-sea environment with water 100 to 500 feet deep. A slightly shallower depth, perhaps 50 to 500 feet, is suggested by unit II Foraminifera (W. W. Rau, written commun., 1966). Molluscan evidence (W. O. Addicott, written commun., 1965) suggests a middle to outer shelf environment for the western part of unit I. Unit II megafossil genera having species currently living in the northeastern Pacific Ocean suggest a sublittoral environment with water depths of about 100 to 300 feet. In addition, the molluscan assemblage of unit II suggests that a warmer climate, similar to the modern shallow-water climate on the Pacific Coast of northern Baja California, Mexico, existed in coastal Washington in early to middle Miocene time.

Unit I is interpreted as a relatively deep-water offshore facies of the Astoria, and unit II with its sandier character, more distinct bedding, and rich molluscan fauna as a nearshore, shallow-

TABLE 12.—*Foraminifera from Astoria*

[Identifications by W. W. Rau. Fossil localities F–51 to F–57 shown

Fossil localities
Washington Div. Mines and Geology Lab. No
Baggina washingtonensis Rau
Bolivina cf. *B. advena* Cushman
astoriensis Cushman, R. E. and Stewart, K. C
cf. *B. brevior* Cushman
marginata adelaidana Cushman and Kleinpell
Buccella mansfieldi oregonensis (Cushman, R. E. and Stewart, K. C.)
Bulimina alligata Cushman and Laiming
ovata d'Orbigny
Buliminella subfusiformis Cushman
Cassidulina crassipunctata Cushman and Hobson
cf. *C. quadrata* Cushman and Hughes
Cibicides aff. *C. perlucida* Nuttall
Dentalina spp
Ellipsonodosaria cf. *E. cocoaensis* (Cushman)
Elphidium cf. *E. minutum* Cushman
Epistominella pacifica (Cushman)
parva (Cushman and Laiming)
Gaudryina alazanensis Cushman
Globigerina spp
Guttulina problema d'Orbigny
Gyroidina orbicularis planata Cushman
Listerella communis (d'Orbigny)
Marginulina subbullata Hantken
Nonion costiferum (Cushman)
Nonionella miocenica Cushman
Planularia astorienesis Cushman, R. E. and Stewart, K. C
Plectofrondicularia billmani Rau
californica Cushman and Stewart
packardi multilineata Cushman and Simonson
Pseudoglandulina inflata (Bornemann)
Quinqueloculina imperialis Hanna and Hanna
weaveri Rau
Robulus spp
Siphogenerina kleinpelli Cushman
Sphaeroidina variabilis Reuss
Uvigerina garzaensis Cushman and Siegfus
Uvigerinella californica ornata Cushman
cf. *U. californica ornata* Cushman
obesa impolita Cushman and Laiming
Valvulineria araucana (d'Orbigny)
menloensis Rau
Virgulina sp

Knappton quadrangle; Saucesian or Relizian Age:
[1] NW¼NW¼ sec. 11, T. 10 N., R. 9 W.
[2] NE¼SW¼ Sec. 10, T. 10 N., R. 9 W.
[3] SW¼SW¼ sec. 11, T. 10 N., R. 9 W.

water facies partly contemporaneous with unit I. As the basin filled, the nearshore facies, represented by unit II in the Eden Valley area, moved westward over the offshore facies (unit I). Farther north, parallelism of unit II with the fault that bounds the Astoria on the east suggests that the basin deepened westward along a north-south hinge parallel to the fault. Nearshore sediments of unit II, locally winnowed by waves or currents, were deposited in the shallower eastern part of the basin and are represented by eastward-thinning sandstone and siltstone on Altoona Ridge in the eastern half of the quadrangle.

At approximately the same time that the nearshore facies (unit II) was being deposited in the eastern part of the map area, the mud and sand of unit III were being deposited near the west edge

Formation, Grays River area, Washington

in fig. 4. C, common; F, few; R, rare; ?, identification questionable]

F–48[1]	F–49[2]	F–50[3]	F–51	F–52	F–53	F–54	F–55	F–56	F–57	F–58[4]	F–59[5]	F–60[6]
4261	4267	4208	3914A	3915	4349	3895	4207	4259A	4032	4262	4266	4265
---	---	---	---	---	---	---	---	---	?	---	R	---
---	R	---	F	---	?	---	?	---	F	---	---	F
---	---	---	---	C	---	F	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	R
---	---	---	---	---	---	---	---	---	---	F	---	---
?	F	F	---	F	---	R	---	C	---	---	---	?
---	---	---	---	---	---	---	---	---	---	F	---	---
---	---	---	C	F	---	---	---	---	---	---	F	F
---	---	---	---	F	---	---	---	---	C	---	---	---
---	C	---	C	---	R	F	---	C	---	C	---	---
---	---	---	---	---	---	---	---	---	---	---	---	R
---	F	---	---	---	R	?	---	---	---	---	---	---
---	R	---	---	---	F	---	---	---	---	R	---	---
---	?	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	F	---	---	---	?
---	---	---	---	---	---	---	---	---	---	---	---	F
---	---	---	---	---	---	---	---	---	R	---	---	---
---	R	R	---	---	---	---	---	---	---	---	---	---
---	---	---	R	F	---	R	---	---	F	R	---	---
---	---	---	---	---	R	---	---	---	---	---	---	---
---	---	---	---	---	F	---	---	---	---	---	---	---
---	---	---	---	---	R	---	---	---	---	---	---	---
---	---	---	---	---	?	---	---	---	---	---	---	---
F	---	C	F	C	---	F	?	C	---	---	---	---
---	---	---	C	F	---	R	---	---	R	---	---	R
---	---	---	---	---	---	---	---	---	---	F	---	---
---	F	F	---	---	---	---	---	---	---	---	---	---
---	---	R	---	---	---	---	---	---	---	R	---	---
---	---	---	---	---	?	---	---	---	---	---	---	---
R	---	---	?	---	---	---	---	---	---	---	---	---
---	?	?	---	---	---	---	---	---	---	---	---	---
---	---	---	---	F	---	---	---	---	---	---	---	---
R	F	C	---	C	R	R	---	R	---	R	---	---
---	---	R	---	---	---	---	C	---	R	---	?	---
---	---	---	---	---	R	---	---	---	---	---	---	---
---	---	---	---	---	C	---	---	---	---	---	---	---
---	---	---	---	---	---	R	R	---	---	---	---	F
---	---	---	---	---	C	---	---	---	---	---	---	---
---	F	---	---	---	---	---	F	---	---	F	---	---
---	R	---	---	---	---	---	F	---	---	R	---	---
---	---	---	---	---	---	R	---	---	R	---	---	---
---	---	---	R	---	---	---	---	---	---	---	---	R

Knappton quadrangle; Saucesian or Relizian Age:
[4] NE¼SW¼ sec. 2, T. 9 N., R. 9 W.
[5] NW¼NW¼ sec. 15, T. 10 N., R. 9 W.
[6] SE¼SE¼ sec. 14, T. 10 N., R. 9 W.

of the quadrangle, possibly in a deep-water, offshore setting. Foraminifera from the southern outcrop area of unit III just west of the quadrangle (including locality F–58, table 12) suggest an open-sea environment with water depths of 500 to 2,000 feet (W. W. Rau, written commun., 1966). The only megafossils found in unit III were mud pectens at a single locality (M–37, table 13); occurring alone, these fossils suggest deposition at bathyal depths (W. O. Addicott, oral commun., 1966). Foraminifera from Rocky Point (F–57, table 12) and from the upper part of unit III on the ridge south of Salmon Creek (F–59, 60, table 12) indicate shallower water depths, 100 to 500 feet and 50 to 300 feet, respectively. Unit III sandstones may have been deposited in relatively deep water, perhaps by turbidity currents. This conclusion is supported as follows: Faunal evidence of bathyal depth (at least

TABLE 13.—*Megafossils from Astoria*

[Identifications by W. O. Addicott. Fossil localities shown in fig. 4, except as noted. X, present preserved for definite identification; aff, comparable but different form; sp, species not determinable; ?

Fossil localities	M–22	M–23	M–24
U.S.G.S. Cenozoic locality	M2780	M2509	M2788
Echinoid:			
Periaster? sp	X	---	---
Gastropods:			
Acteon boulderanus Etherington	---	---	---
Bruclarkia oregonensis (Conrad)	---	---	---
oregonensis forma *yaquinana* (Anderson and Martin)	---	---	---
Calyptraea sp	---	---	---
Cancellaria cf. *C. oregonensis* (Conrad)	---	---	---
Comitas? n. sp. aff. *C. spencerensis* Moore	---	---	X
Crepidula rostralis (Conrad)	---	---	---
Cryptonatica oregonensis (Conrad)	---	---	---
Cylichna sp	---	X	---
Cylichnina petrosa (Conrad)	---	---	---
Ficus modesta Conrad	---	---	---
Haminoea articensis Addicott	---	X	---
Hanetia? n. sp	---	---	---
Liricassis petrosa (Conrad)	sp	X	X
Molopophorus? sp	---	---	---
Nassarius lincolnensis (Anderson and Martin)	---	---	---
Natica cf. *N. vokesi* Addicott	---	---	---
Naticid	---	X	---
"*Neptunea*" *diminuta* Etherington	---	---	---
Odostomia sp	---	---	---
Oenopota? sp	---	---	---
Ophiodermella temblorensis (Anderson and Martin)	---	cf	---
n. sp	---	---	---
Polinices canalis Moore	---	---	---
cf. *P. galianoi* Dall	---	---	---
Priscofusus geniculus (Conrad)	X	?sp	---
Psephaea (*Miopleiona*) *indurata* (Conrad)	---	X	---
Scaphander? sp	---	---	---
Searlesia? sp	---	---	---
Spirotropis washingtonensis Etherington	---	---	---
Trochita n. sp	---	---	---
Trophon sp	---	---	---
Turrid	---	---	---
Turritella oregonensis (Conrad)	---	---	---
Pelecypods:			
Acila (*Acila*) *gettysburgensis* (Reagan)	X	X	---
(*Truncacila*) *conradi* (Meek)	sp	---	---
Anadara cf. *A. devincta* (Conrad)	---	---	---
Chione? sp	---	---	---
Crenella cf. C. *porterensis* Weaver	---	---	---
Cyclocardia cf. *C. subtenta* (Conrad)	---	sp	---
Delectopecten peckhami (Gabb) Arnold	---	---	---
Dosinia cf. *D. whitneyi* (Gabb)	---	---	---
Glycymeris sp	---	---	---
Katherinella angustifrons (Conrad)	---	---	---
Lucinoma acutilineata (Conrad)	X	X	---
Macoma albaria (Conrad)	X	X	sp
arctata (Conrad)	---	---	---
astori Dall	---	---	---
twinensis Clark	---	X	---
Nucula n. sp. Moore (1963)	---	---	X
sp	---	---	---
Nuculana (*Litorhadia*) *astoriana* (Henderson)	---	---	---
(*Saccella*) *calkinsi* Moore	---	---	---
(*Sacella*) *ochsneri elmana* Etherington	---	---	---
Nuculanid	---	---	---
Panope abrupta (Conrad)	---	---	---
Patinopecten propatulus (Conrad)	---	---	---
Securella cf. *S. ensifera* (Dall)	---	---	---
Solemya (*Archarax*) *ventricosa* Conrad	---	X	---
Solen conradi Dall	---	---	---
Spisula albaria (Conrad)	---	---	---
Tellina emacerata Conrad	---	---	---
Tellinid	---	---	---
Thracia trapezoides Conrad	---	---	---
Thyasira bisecta (Conrad)	---	---	---
Venerid	---	---	---
Vertipecten fucanus (Dall)	---	---	---
Yoldia sp	---	---	---
Scaphopods:			
Dentalium cf. *D. pseudonyma* Pilsbry and Sharp	sp	---	X
schencki Moore	---	X	---

[1] SE¼NW¼ sec. 12, T. 9 N., R. 7 W., Skamokawa quad.
[2] SE¼NE¼ sec. 35, T. 10N., R. 9W., Knappton quad.

Formation, Grays River area, Washington

as identified; ?, doubtful identification; cf, similar form, specimen(s) incomplete or too poorly sp, genus questionably identified]

M-25	M-26	M-27	M-28	M-29	M-30	M-31	M-32	M-33	M-34	M-35	M-36[1]	M-37[2]
M2790	M2781	M2548	M2512	M2792	M2517 M2588	M2514	M2783	M2587	M2516	M2567	M2513	M2515
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	cf	---	---	---	---	X	---
---	---	---	cf	---	X	---	cf	---	cf	---	X	---
---	---	cf	---	---	---	---	---	---	---	---	X	---
---	X	---	---	---	---	---	---	?	---	---	---	---
sp	---	sp	---	---	---	---	---	---	X	?sp	X	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	---	sp	---	X	?sp	cf	cf	X	---	X	---
---	---	---	---	---	---	---	---	---	---	?sp	---	---
---	---	---	---	---	---	X	---	---	---	---	X	---
---	X	X	---	---	---	---	---	---	---	---	X	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	?sp	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
cf	---	---	---	---	---	---	---	---	?	sp	X	---
---	---	---	---	---	---	---	---	X	---	---	---	---
X	X	X	---	---	---	X	X	X	---	X	---	---
---	---	---	---	---	---	X	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	---	---	---	---	X	---	---	---	---	---	---
---	---	---	---	---	---	---	---	?	---	---	X	---
---	---	---	---	---	---	X	?	X	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	X	---	---	---	?sp	sp	---	---	---	---	---
---	X	---	---	---	---	X	---	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
---	---	---	---	---	---	---	X	---	---	---	---	---
---	---	---	---	---	---	---	?sp	---	---	---	X	---
---	---	---	---	---	---	---	X	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	---	---	---	---	---	---	---	---	---	X	---
X	---	X	---	---	X	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	X	---	---	---	---	---	---	sp	---	cf	---
---	---	sp	---	---	---	X	X	sp	sp	---	X	---
---	---	---	---	---	---	X	---	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
sp	sp	sp	---	---	---	X	---	sp	---	---	---	---
---	---	---	---	---	---	---	---	---	---	?sp	---	X
---	---	---	---	---	---	---	---	---	X	---	---	---
---	---	---	---	---	---	X	---	---	---	---	---	---
---	?	X	---	sp	X	X	X	X	X	---	---	---
sp	---	sp	---	---	---	?sp	X	---	sp	---	---	---
---	---	cf	---	---	---	X	X	X	---	X	---	---
---	X	X	---	cf	---	---	---	---	---	---	---	---
---	---	---	---	cf	---	---	---	---	---	---	X	---
---	---	---	sp	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	X	---	---	---	---
---	---	X	---	---	---	---	---	---	---	---	---	---
---	sp	cf	---	---	---	---	---	sp	X	sp	---	---
---	---	X	---	---	---	---	X	---	---	---	---	---
---	---	---	X	---	---	---	---	---	---	---	---	---
---	---	X	---	---	---	X	X	cf	cf	---	---	---
---	---	X	---	---	---	?cf	---	?	---	---	---	---
---	X	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	X	---	---	---	---	sp	---	?sp	---	cf	---
---	---	---	---	---	---	sp	X	---	cf	---	X	---
---	X	X	---	---	---	---	---	---	X	---	X	---
---	---	---	X	---	X	---	---	---	---	---	---	---
---	X	X	---	---	X	X	X	X	---	---	---	---
X	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	X	---	---	---
---	---	---	---	---	---	?cf	X	---	?	---	---	---
---	---	---	---	---	---	---	---	---	---	---	X	---
---	---	---	---	---	---	---	---	---	---	---	---	---
---	---	---	---	---	---	---	---	---	---	---	---	---

in part), the extensive development of parallelism in lamination and bedding, and the general absence of shallow-water features such as large-scale crossbedding and rich molluscan faunas.

The contrast in composition between the offshore (units I and III) and nearshore (unit II) facies suggests that more than one route of sand transport to the Grays River area may have existed. The heavy minerals of units I and III and the relatively abundant potassium feldspar of unit III could have been derived from granitic and high-grade metamorphic rocks, such as those exposed north of the Columbia Plateau in northeastern Washington and nearby British Columbia. Unit II undoubtedly includes similar source rocks, but the high hornblende-epidote content of its heavy minerals and its higher plagioclase content indicate that amphibolites and hornblende gneisses such as those of the northern Cascade Range were also significant source rocks.

MIOCENE TO PLIOCENE(?) SERIES

BASALT FLOWS AND INTRUSIVE ROCKS

Basalt flows approximately 500 feet thick overlie the Astoria Formation in the southern part of the quadrangle. The flows are divided into two units, basalt of Three Tree Point and basalt of Altoona, on the basis of lithology, chemistry, and fabric. Intrusive rocks in the southern two-thirds of the quadrangle include the two petrochemical types recognized in the flows, as well as a third petrochemical type informally designated Pack Sack type because of its similarity to the basalt at Pack Sack lookout (Wagner, 1967a).

LITHOLOGY

Extrusive and Intrusive Basalt of Three Tree Point type

Basalt of Three Tree Point is exposed along the Columbia River in the southeastern part of the quadrangle at Three Tree Point and eastward. It consists largely of massive to hackly basalt but also contains some flow breccia and pillow lava. Some intrusive rock may have been mapped with the extrusive unit in its westernmost exposures. The basalt is black and aphanitic in the flows and in the smaller related intrusives. Larger related intrusives such as the mass on the Columbia River bank immediately east of Brookfield or the sill at Elk Mountain have a fine-grained sugary texture.

The basalt of Three Tree Point and the related small intrusives are hyalo-ophitic rocks (fig. 17) in which volcanic glass with

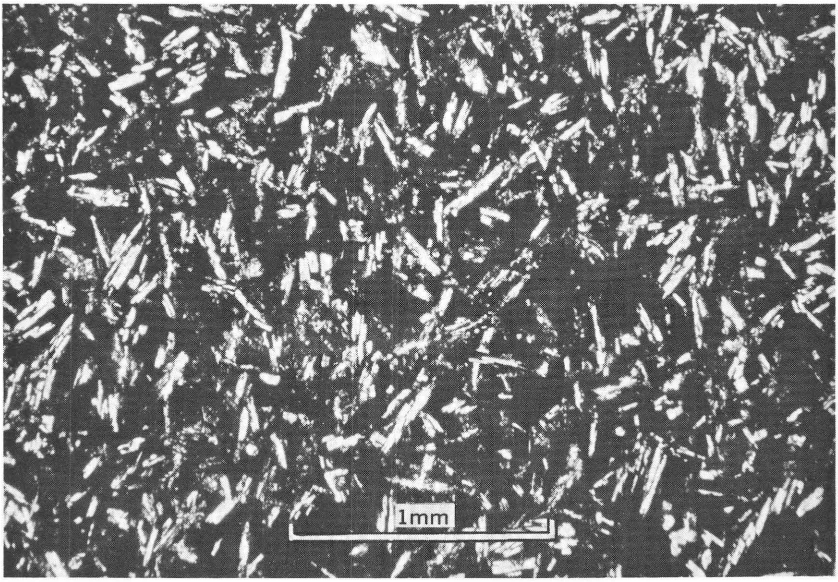

FIGURE 17.—Photomicrograph of basalt of Three Tree Point. Hyalo-ophitic basalt consisting mainly of magnetite- or ilmenite-rich glass, plagioclase, and augite. Plane-polarized light.

abundant magnetite or ilmenite commonly is 40 to 50 percent of the total volume. Plagioclase (approximately An_{45-55}) is about 30 to 35 percent, and augite (N_y=1.70 to 1.71; $2V$=32° to 54°) 20 to 25 percent of the total volume. Pigeonite is present in some rocks, and less than 2 percent of calcite occurs locally in the rocks. Absence of olivine distinguishes basalt of Three Tree Point type from basalts of Altoona and Pack Sack types. The large intrusive masses are holocrystalline and contain interstitial alkali feldspar.

Chemical analyses of basalt of Three Tree Point type are given in table 14 (columns 15 to 25) and in figure 18. The Three Tree Point type is characterized by high silica and alkali content. Normative quartz and orthoclase values are high, averaging 10 and 9 percent, respectively. Normative plagioclase is calcic andesine, averaging An_{42} in composition. The Three Tree Point type most nearly approaches the average andesite or tholeiitic andesite in the grouping of Nockolds (1954, table 6). Fused glass beads made from basalt of Three Tree Point type have an index of refraction from 1.576 to 1.585, significantly lower than that of glass beads made from basalts of Altoona and Pack Sack types (McKee, 1968).

TABLE 14.—*Chemical analyses and normative compositions in weight percent of basalt of Three Tree Point type from the Grays River area and of similar basalt from other areas*

[Analyses recalculated to water-free basis; 15–24 by methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith. Location of 15–21 shown in fig. 4]

	15	16	17	18	19	20	21	22	23	24	25	26	27
Chemical analyses													
SiO_2	55.6	56.0	55.4	56.6	55.2	56.0	56.0	56.2	55.9	56.8	56.0	55.9	54.5
Al_2O_3	14.2	14.6	13.7	14.0	13.4	13.9	14.0	13.1	13.9	14.5	13.9	14.1	14.1
Fe_2O_3	1.0	1.1	4.3	2.7	2.7	3.9	3.1	3.7	2.4	1.5	2.6	2.2	2.6
FeO	9.6	10.0	8.2	9.3	10.2	8.6	9.5	9.1	9.6	9.9	9.4	9.9	9.4
MgO	4.0	3.8	4.0	3.2	4.1	3.2	3.4	3.8	3.8	3.6	3.7	3.6	4.2
CaO	7.3	7.0	6.9	7.0	6.7	6.7	6.8	6.6	6.9	6.5	6.8	7.1	8.0
Na_2O	3.3	3.3	3.2	3.0	2.9	3.0	2.7	3.1	3.1	3.4	3.1	3.3	3.0
K_2O	1.3	1.3	1.4	1.6	1.8	1.6	1.7	1.6	1.5	1.5	1.5	1.3	1.5
TiO_2	1.8	1.8	2.3	1.9	2.3	2.0	2.0	2.0	2.1	1.8	2.0	2.0	2.0
P_2O_5	.39	.36	.49	.39	.49	.37	.46	.44	.49	.35	.42	.36	.4
MnO	.20	.20	.16	.20	.17	.71	.20	.11	.19	.19	.23	.21	.2
CO_2	1.2	.53	.11	-----	-----	-----	-----	.29	.05	-----	.22	-----	-----
H_2O-	.32	.34	.86	.57	.41	.54	.38	.53	.66	.53	-----	-----	} 1.2
H_2O+	1.0	1.0	1.1	.78	.79	.82	1.0	.67	.94	1.0	-----	-----	
Norms													
Q	8.9	8.8	11.3	11.1	8.9	11.6	11.8	11.7	10.2	8.8	10.3	8.8	6.9
Or	7.8	7.8	8.5	9.6	10.8	9.6	10.2	9.6	9.0	9.0	9.2	7.7	9.0
Ab	28.3	27.5	26.8	25.7	24.8	25.7	23.1	26.6	25.8	28.4	26.3	28.0	25.7
An	19.8	21.4	18.9	19.7	17.9	19.4	20.8	16.8	19.8	20.1	19.4	19.8	20.3
Wo	2.6	3.2	4.6	5.2	5.0	4.7	4.1	4.7	4.6	4.1	4.3	5.5	7.0
En	9.8	9.3	9.9	8.1	10.1	8.1	8.6	9.3	9.4	8.9	9.2	9.0	10.3
Fs	14.2	14.9	8.1	12.1	13.0	10.6	11.9	10.6	12.4	14.2	12.2	13.5	12.2
Mt	1.5	1.6	6.2	4.0	4.0	5.6	4.6	5.3	3.5	2.2	3.9	3.2	3.8
Il	3.5	3.5	4.3	3.7	4.4	3.8	3.8	3.8	4.1	3.5	3.8	3.8	3.8
Ap	.9	.8	1.2	.9	1.2	.9	1.1	1.0	1.2	.8	1.0	.9	1.0
Cc	2.8	1.2	.3	-----	-----	-----	-----	.7	.1	-----	.5	-----	-----
Normative plagioclase	An_{41}	An_{44}	An_{41}	An_{43}	An_{42}	An_{43}	An_{47}	An_{39}	An_{43}	An_{41}	An_{42}	An_{41}	An_{44}

15. Basalt of Three Tree Point, Three Tree Point, NW¼ sec. 14, T. 9 N., R. 7 W. Field No. WoGR65–919; USGS Lab. No. 165978.
16. Basalt intrusive, NE¼ sec. 18, T. 9 N., R. 7 W., Field No. WoGR65–1035; USGS Lab. No. 165979.
17. Basalt intrusive, SW¼NW¼ sec. 15, T. 9 N., R. 7 W. Field No. WoGR64–442; USGS Lab. No. 164281.
18. Basalt sill, NW¼NE¼ sec. 31, T. 11N., R. 7 W. Field No. WGR63–199, USGS Lab. No. 162217.
19. Basalt sill, Elk Mountain, SE¼SE¼ sec. 21, T. 10 N., R. 7 W. Field No. WoGR64–523; USGS Lab. No. 164287.
20. Basalt intrusive, NE¼SE¼ sec. 22, T. 10 N., R. 8 W. Field No. WGR63–343; USGS Lab. No. 162218.
21. Basalt dike, NW¼SW¼ sec. 3, T. 10 N., R. 7 W. Field No. WGR63–71; USGS Lab. No. 162215.
22. Basalt intrusive at Portugese Point ,NE¼SE¼ sec. 10, T. 9 N., R. 9 W., Knappton 7½′ quadrangle, Washington. Field No. WoR64–13; USGS Lab. No. 164299.
23. Basalt sill at Lane Creek, NW¼NW¼ sec. 3, T. 10 N., R. 9 W., Oman Ranch 7½′ quadrangle, Washington. Field No. WoR64–9; USGS Lab. No. 164296.
24. Basalt sill, Bear River Ridge, SE¼SE¼ sec. 10, T. 10 N., R. 10 W., Chinook 7½′ quadrangle, Washington. Field No. McKFC65–238; USGS Lab. No. 165982.
25. Average of columns 1 to 10.
26. Tholeiitic basalt, lowest unit of Miocene volcanic rocks, central part of Oregon Coast Range, average of 8 analyses (Snavely and others, 1965, table 1).
27. Yakima Basalt exclusive of late Yakima petrographic type, Columbia Plateau, average of 8 analyses from Waters (1961, table 5).

Figure 18 shows the very close similarity between the Three Tree Point type and the average composition of basalt in the lower unit of Miocene volcanic rocks in the Oregon Coast Range (Snavely and others, 1965, table 1). Average water-free values for Yakima Basalt of the Columbia River Group exclusive of the late Yakima petrographic type (Waters, 1961, table 5) are also plotted in figure 18 for comparison. Except for its slightly lower silica content, the Yakima Basalt shows striking chemical similarity to basalt of Three Tree Point type as well as to the lower unit of Miocene volcanic rocks in the Oregon Coast Range, as noted previously (Snavely and others, 1965, p. 114).

Extrusive and Intrusive Basalt of Altoona Type

Basalt of Altoona type is exposed along the Columbia River between Altoona and Jim Crow Point. In contrast to the basalt of Three Tree Point, it is predominantly flow breccia with small amounts of pillow lava and massive basalt. Some of the basaltic breccia mapped as basalt of Altoona type may be shallow intrusive rock closely associated with the flows. The basalt is fresh, black, and aphanitic. Sparse plagioclase phenocrysts as large as half an inch in diameter occur in the flows and in the small intrusive bodies of basalt of Altoona type.

Basalt of Altoona type is hyalo-ophitic (fig. 19). Glass with abundant fine opaque minerals commonly makes up 50 to 60 percent and locally as much as 70 percent (analysis 28, table 15) of the total volume. Typically, plagioclase (approximately An_{60}) makes up about 22 to 28 percent, augite (N_y=approximately 1.71; $2V=48°$ to $55°$) about 9 to 14 percent, and olivine, largely altered to mineraloids and clay minerals, about 3 to 6 percent. The high ratio of plagioclase to pyroxene, the presence of olivine, and the occurrence of scattered large plagioclase phenocrysts are distinguishing features of basalt of Altoona type.

The basalt contains small amounts of normative quartz and orthoclase, and the average normative plagioclase composition is An_{46} (table 15). Average chemical composition is close to Nockolds' average tholeiitic andesite (1954, table 6). Figure 18 demonstrates the chemical uniformity of basalt of Altoona type. It is clearly distinct from basalt of Three Tree Point type because of its lower silica content. Basalt of Altoona type contains more iron, alkalis, titanium, and phosphate, and less aluminum, magnesium, and calcium than basalt of Pack Sack type. Fused glass beads of basalt of Altoona type range in index of refraction from 1.595 to 1.603, significantly higher indices of refraction than beads made from basalt of Three Tree Point type, but their refractive indices coincide in part with those of beads made from basalt of Pack Sack type (McKee, 1968).

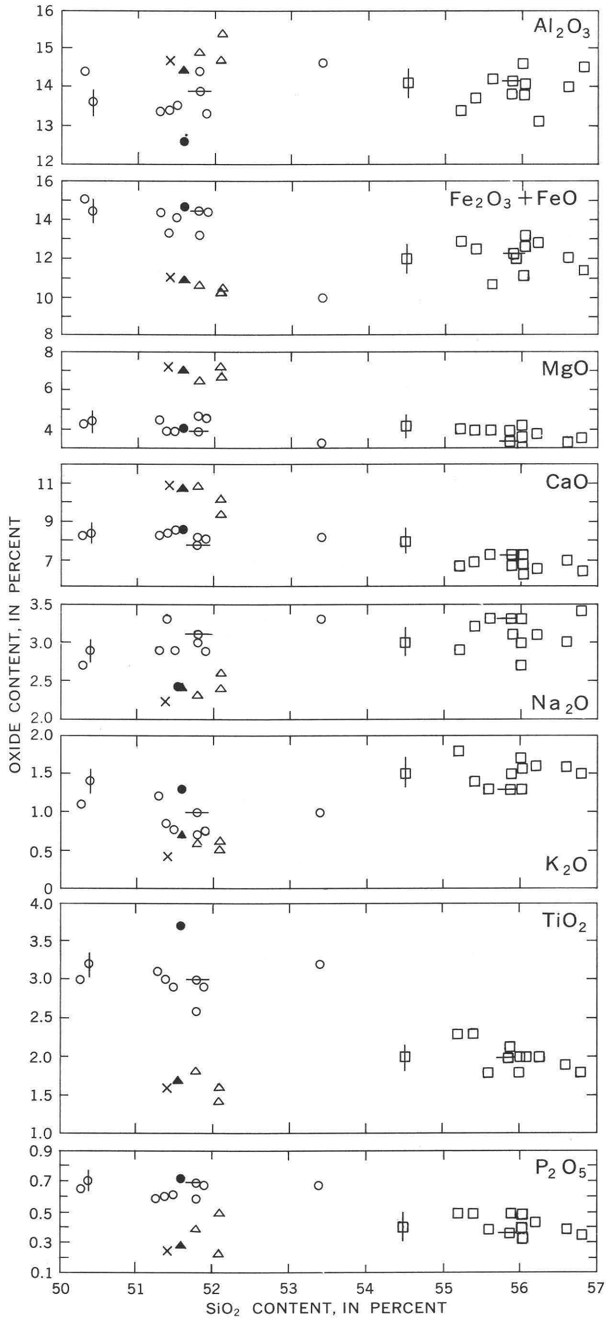

FIGURE 18.—Silica variation diagrams—basalt flows and intrusive rocks. (Analyses recalculated to water-free basis.)

EXPLANATION

△

Pack Sack type basalt

▲

Pomona Basalt of Schmincke (1967), NW¼ SE¼ sec. 19, T. 11 N., R. 23 E., 10.4 miles north of Sunnyside, Wash., from Schmincke (1967, table 4)

×

Basalt at Pack Sack lookout, sec. 1, T. 14 N., R. 7 W., Raymond quadrangle, Wash., from H. C. Wagner (written commun., 1967)

○

Altoona-type basalt, Grays River quadrangle and vicinity, Washington

-o-

Tholeiitic basalt, upper unit of Miocene volcanic rocks, central part of Oregon Coast Range, average of 11 analyses, from Snavely, Wagner, and MacLeod (1965, table 1)

ϕ

Late Yakima petrographic type, Columbia Plateau, average of 4 analyses, from Waters (1961, table 5)

●

Elephant Mountain Basalt of Schmincke (1967), SW¼SW¼ sec. 33, T. 10 N., R. 20 E., central Washington, from Schmincke (1967, table 4)

□

Three Tree Point type basalt from Grays River quadrangle and vicinity, Washington

-□-

Tholeiitic basalt, lower unit of Miocene volcanic rocks, central part of Oregon Coast Range, average of 8 analyses, from Snavely, Wagner, and MacLeod, (1965, table 1)

ф

Yakima Basalt exclusive of late Yakima petrographic type, Columbia Plateau, average of 8 analyses, from Waters (1961, table 5).

FIGURE 18.—Continued.

As shown in figure 18, basalt from the upper unit of Miocene volcanic rocks in the central part of the Oregon Coast Range (Snavely and others, 1965, table 1) is virtually identical chemically with basalt of Altoona type. Snavely, Wagner, and MacLeod (1965, p. 114) have pointed out the similarity between their upper unit and the late Yakima type of the Columbia River Group. In figure 18 an average of four analyses of the late Yakima petrographic type of the Columbia River Group (Waters, 1961, table 5), as well as an analysis of an upper Yakima flow in south-central Washington, the Elephant Mountain Basalt of Schmincke (1967, table 4), show marked similarity to basalt of Altoona type.

PACK SACK TYPE INTRUSIVE ROCKS

Basalt of Pack Sack type, so-called because of its chemical similarity to the basalt at Pack Sack lookout (H. C. Wagner, written commun., 1967), is represented by a 200- to 300-foot-thick sill be-

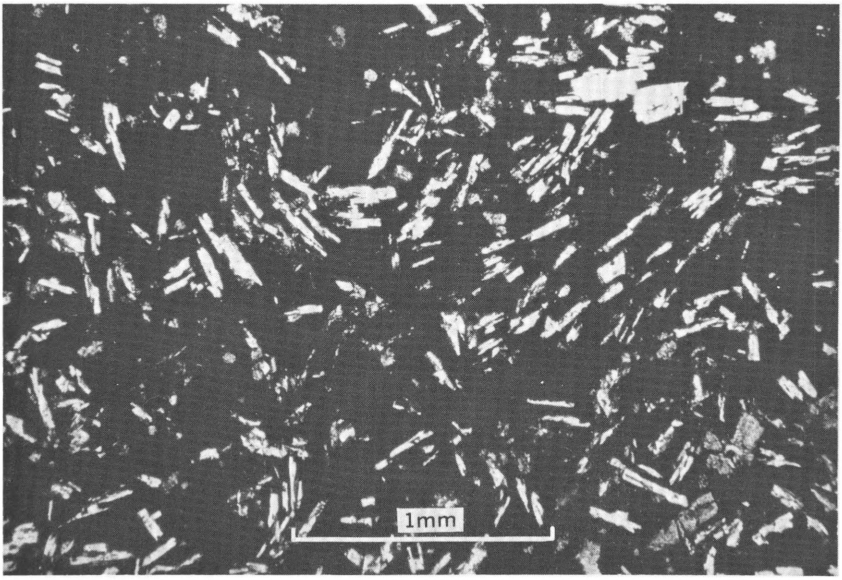

FIGURE 19.—Photomicrograph of basalt of Altoona type. Glassy basalt with microlites of plagioclase, augite, and minor olivine. Plane-polarized light.

tween Salmon and Sisson Creeks in the southwestern part of the Grays River quadrangle and by an intrusive approximately 6 miles to the north in secs. 14 and 23, T. 11 N., R. 9 W., which is part of a much thicker sill extensively exposed west of the map area.

The intrusive between Salmon and Sisson Creeks is a black microporphyritic basalt with aphanitic groundmass. The basalt is brecciated in places, and the fractures are filled with carbonate minerals. Apophyses of thoroughly decomposed basalt in the siltstone immediately above the upper contact suggest that the mass is intrusive.

Basalt from the southern sill is intersertal to hyalo-ophitic, microporphyritic, and in part slightly trachytic (fig. 20). Subparallel plagioclase phenocrysts (approximately An_{65}) are scattered in a groundmass containing small randomly oriented to subparallel plagioclase laths (approximately An_{45}), granules of clinopyroxene ($N_y=1.70$; $2V$ approximately 54°) and olivine (estimated $2V$ on phenocryst suggests composition of approximately Fo_{85}), and abundant opaque-dusted glass. An average of two point counts on basalt from the southern sill gives the following composition:

	Volume percent
Plagioclase phenocrysts	3.0
Plagioclase microlites	23.0
Clinopyroxene granules	19.2
Olivine phenocrysts	.7
Olivine granules	1.8
Glass and opaque minerals	51.9
Carbonate	.4
	100.0

TABLE 15.—*Chemical analyses and normative compositions, in weight percent, of basalt of Altoona type from the Grays River area and of similar basalt from other areas*

[Analyses recalculated to water-free basis; analyses 28–34 were done by methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith. Location of 28–32 shown in fig. 4]

	28	29	30	31	32	33	34	35	36	37	38
Chemical analyses											
SiO_2	53.4	51.4	51.5	50.3	51.9	51.3	51.8	51.7	51.8	50.4	51.6
Al_2O_3	14.6	13.4	13.5	14.4	13.3	13.4	14.4	13.9	13.9	13.6	12.6
Fe_2O_3	1.7	1.0	2.4	4.8	1.9	2.6	1.5	2.3	3.5	1.9	2.1
FeO	8.3	12.3	11.7	10.3	12.5	11.8	11.7	11.2	11.0	12.6	12.6
MgO	3.3	3.9	3.9	4.3	4.6	4.5	4.7	4.2	3.9	4.4	4.1
CaO	8.2	8.4	8.6	8.3	8.1	8.3	8.1	8.3	7.9	8.4	8.6
Na_2O	3.3	3.3	2.9	2.7	2.9	2.9	3.0	3.0	3.1	2.9	2.4
K_2O	1.0	.87	.79	1.1	.77	1.2	.71	.92	1.0	1.4	1.3
TiO_2	3.2	3.0	2.9	3.0	2.9	3.1	2.6	3.0	3.0	3.2	3.7
P_2O_5	.67	.60	.61	.64	.67	.59	.59	.62	.69	.7	.72
MnO	.14	.23	.22	.22	.19	.21	.22	.20	.23	.25	.19
CO_2	2.3	1.7	1.1	-----	.19	.10	.73	.87	-----	.09	-----
H_2O-	.90	.31	.64	1.6	.11	.46	.41	-----	-----	.9	.35
H_2O+	1.8	1.5	1.5	1.4	1.3	.64	1.4	-----	-----		.52
Norms											
Q	12.0	5.4	7.7	6.0	5.3	4.0	5.4	6.5	6.3	1.7	8.9
C	.1	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Or	6.1	5.1	4.6	6.7	4.6	7.2	4.2	5.5	5.9	8.3	7.8
Ab	27.9	27.7	24.2	22.7	24.9	24.9	25.0	25.3	26.2	24.8	20.6
An	21.7	19.3	21.7	23.8	20.8	19.7	23.8	21.5	21.1	19.9	19.9
Wo	-----	3.1	4.1	5.4	5.8	7.1	3.4	4.1	5.7	6.9	7.8
En	8.2	9.7	9.7	10.8	11.4	11.1	11.7	10.4	9.7	11.1	6.9
Fs	8.8	17.2	15.2	10.5	16.8	14.6	16.5	14.2	12.8	16.7	15.1
Mt	2.4	1.5	3.4	6.9	2.8	3.8	2.2	3.3	5.1	2.8	4.2
Il	6.1	5.6	5.4	5.7	5.6	6.0	4.8	5.6	5.7	6.1	7.0
Ap	1.6	1.4	1.5	1.5	1.6	1.4	1.4	1.5	1.6	1.7	1.7
Cc	5.2	4.0	2.6	-----	.4	.2	1.7	2.0	-----	.2	-----
Normative plagioclase	An_{44}	An_{41}	An_{47}	An_{51}	An_{46}	An_{44}	An_{44}	An_{46}	An_{45}	An_{45}	An_{49}

28. Basalt of Altoona, breccia, SE¼SE¼ sec. 18, T. 9 N., R. 7 W. Field No. WoGR65–732A; USGS Lab. No. 165379.
29. Basalt of Altoona, massive, SE¼SE¼ sec. 18, T. 9 N., R. 7 W. Field No. WoGR65–732; USGS Lab. No. 165378.
30. Basalt of Altoona, breccia, NW¼NE¼ sec. 16, T. 9 N., R. 8 W. Field No. WGR63–391; USGS Lab. No. 162224.
31. Basalt dike, SW¼SE¼ sec. 14, T. 10 N., R. 7 W. Field No. WGR63–9; USGS Lab. No. 162214.
32. Basalt intrusive, NE¼SE¼ sec. 32, T. 10 N., R. 7 W. Field No. WoGR64–527; USGS Lab. No. 164288.
33. Basalt intrusive, SE¼SW¼ sec. 7, T. 10 N., R. 6 W., Skamokawa quadrangle, Washington. Field No. WoR64–17; USGS Lab. No. 164300.
34. Basalt intrusive, NW¼SW¼ sec. 2, T. 9 N., R. 4 W., Knappton 7½′ quadrangle, Washington. Field No. WoFC65–61; USGS Lab. No. 165980.
35. Average of columns 1 to 7.
36. Tholeiitic basalt, upper unit of Miocene volcanic rocks, central part of Oregon Coast Range, average of 11 analyses (Snavely and others, 1965, table 1).
37. Late Yakima petrographic type, Columbia Plateau, average of 4 analyses, from Waters, (1961, table 5).
38. Elephant Mountain Basalt of Schmincke (1967), SW¼SW¼ sec. 33, T. 10 N., R. 20 E., central Washington, from Schmincke (1967, table 4).

Basalt from the thicker northern sill is black and finely porphyritic with a fine-grained groundmass. Weathering produces a thick brown rind of altered basalt on outcrop surfaces. The basalt is holocrystalline, intergranular to subophitic; its composition by point count is as follows:

	Volume percent
Plagioclase	45.1
Clinopyroxene	46.8
Olivine	1.5
Opaque minerals	3.0
Clay and mineraloid	3.5
Carbonate	.1
	100.0

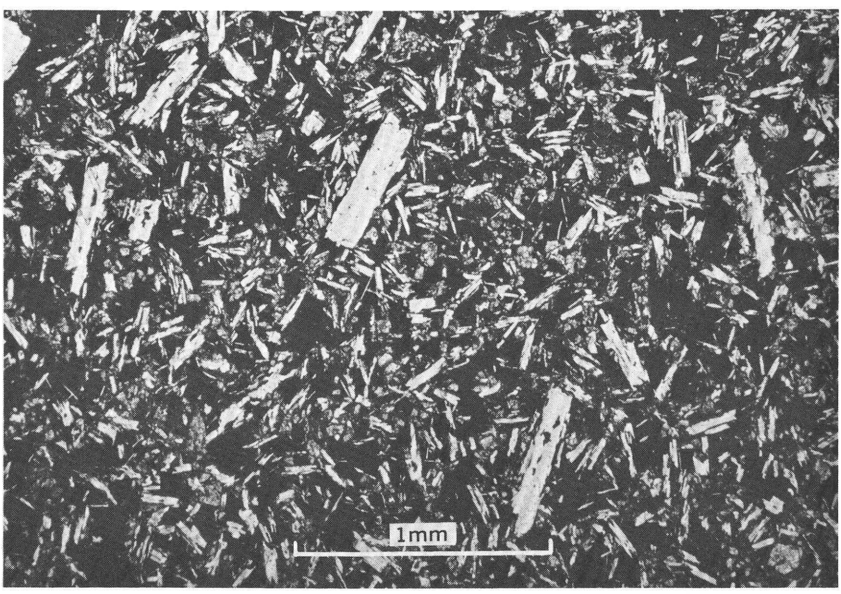

FIGURE 20.—Photomicrograph of basalt of Pack Sack type from sill south of Salmon Creek. Glass-rich microporphyritic basalt with plagioclase, clinopyroxene, and minor olivine. Plane-polarized light.

TABLE 16.—*Chemical analyses and normative compositions, in weight percent, of basalt of Pack Sack type from the Grays River area and of similar basalt from other areas*

[Analyses recalculated to water-free basis; 39–41, 43 by methods described by Shapiro and Brannock (1962), supplemented by X-ray fluorescence. Analysts: P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, Hezekiah Smith. Location of 39–41 shown in fig. 4]

	39	40	41	42	43	44
Chemical analyses						
SiO_2	52.1	51.8	52.1	52.0	51.4	51.6
Al_2O_3	14.7	14.9	15.4	15.0	14.7	14.4
Fe_2O_3	1.0	1.6	1.0	1.2	2.8	1.7
FeO	9.5	9.0	9.4	9.3	8.3	9.2
MgO	6.7	6.5	7.2	6.8	7.3	7.0
CaO	9.4	10.8	10.2	10.1	10.9	10.7
Na_2O	2.6	2.3	2.4	2.4	2.3	2.4
K_2O	.61	.61	.52	.58	.42	.74
TiO_2	1.6	1.8	1.4	1.6	1.6	1.7
P_2O_5	.49	.37	.23	.36	.25	.28
MnO	.14	.16	.18	.16	.16	.17
CO_2	1.1	.12	-----	.4	-----	-----
H_2O-	.20	.29	.27	-----	-----	.63
H_2O+	1.4	.91	.63	-----	-----	.33
Norms						
Q	4.8	3.5	1.8	3.4	3.2	2.1
Or	3.6	3.6	3.0	3.4	2.5	4.5
Ab	21.6	19.7	20.5	20.6	19.4	20.8
An	26.9	28.4	29.5	28.3	28.5	25.5
Wo	4.0	9.3	8.2	7.2	10.0	10.5
En	16.6	16.1	17.9	16.9	18.2	17.6
Fs	14.2	12.5	14.4	13.7	10.6	12.7
Mt	1.5	2.3	1.5	1.8	4.1	2.6
Il	3.1	3.5	2.7	3.1	3.0	3.2
Ap	1.2	.9	.6	.9	.6	.7
Cc	2.6	.3	-----	1.0	-----	-----
Normative plagioclase	An_{55}	An_{59}	An_{59}	An_{58}	An_{59}	An_{55}

39. Basalt sill intruding Astoria Formation in NW¼SW¼ sec. 14, T. 10 N., R. 9 W., Knappton 7½′ quadrangle, Wash. Field No. McKR64–629; USGS Lab. No. 164292.
40. Basalt sill in SW¼NE¼ sec. 23, T. 11 N., R. 9 W., Oman Ranch 7½′ quadrangle, Washington. Field No. WoGR64–492; USGS Lab. No. 164284.
41. Basalt sill in NW¼SE¼ sec. 21, T. 11 N., R. 9 W., Oman Ranch 7½′ quadrangle, Wash. Field No. WoFC65–72; USGS Lab. No. 165981.
42. Average of analyses 1 to 3.
43. Basalt at Pack Sack lookout, sec. 1, T. 14 N., R. 7 W., Raymond quadrangle, Wash., from Wagner, (written commun., 1967).
44. Pomona Basalt of Schmincke (1967), NW¼SE¼ sec. 19, T. 11 N., R. 23 E., 10.4 mile north of Sunnyside, Wash., from Schmincke (1967, table 4).

Chemical analyses of basalt of Pack Sack type are listed in table 16 (columns 39 to 42) and compared with the basalt at Pack Sack lookout (column 43) and Pomona Basalt of Schmincke (1967) from south-central Washington (column 44). Basalt of Pack Sack type corresponds closely to normal tholeiitic basalt of Nockolds (1954, table 7). It contains small amounts of normative quartz and orthoclase, and the normative plagioclase averages An_{58}. Chemical data summarized in figure 18 show that Pack Sack type basalt in the Grays River area is very similar to both the basalt at Pack Sack lookout, Raymond quadrangle, and the Pomona Basalt of Schmincke (1967) of the Columbia Plateau. Basalt of Pack Sack type, like that of Altoona type, clearly differs from basalt of Three Tree Point type in its lower silica content. Ranges of other oxides exclude or nearly exclude basalt of Altoona type. Pack Sack type is richer than Altoona type in oxides of aluminum, magnesium, and calcium, and contains less of all other major oxides except silica. Silica variation diagrams for basalt of south-central Washington (Schmincke, 1967, fig. 17) show the same chemical relationships between Pomona and pre-Pomona basalts that exist between Pack Sack and Altoona types (fig. 18). Index of refraction of fused glass beads ranges from 1.593 to 1.598 and overlaps the range determined for basalt of Altoona type (McKee, 1968).

AGE AND CORRELATION

The basalts of Three Tree Point and Altoona rest on the Astoria Formation of early or middle Miocene age. In the central part of the Oregon Coast Range the two volcanic units, chemical correlatives of the basalts of Three Tree Point and Altoona, are regarded as middle Miocene in age (Snavely and others, 1965, pl. 1, p. 112). In the Raymond quadrangle, north of the Grays River quadrangle, pillow basalt of Three Tree Point type, included in the lower part of the Astoria Formation, is interbedded with lower Miocene (Saucesian Stage of Kleinpell, 1938) strata (H. C. Wagner, written commun., 1967).

Basalt at Pack Sack lookout in the Raymond quadrangle overlies strata containing mollusks of probable middle to late Miocene age; overlying strata contain a molluscan fauna of late Miocene or early Pliocene age (H. C. Wagner, written commun., 1967).

Petrochemically, the basalt flows and intrusive rocks of the Grays River area are similar to the Yakima Basalt sequence of the Columbia Plateau. Yakima Basalt, including the late Yakima petrographic type, is regarded as middle Miocene to early Pliocene in age (Waters, 1961, p. 608); potassium-argon dates, summarized by Swanson (1967, p. 1105), indicate an age of approximately 17 to 12 million years for Yakima and late Yakima type flows of the Columbia Plateau.

An age of early or middle Miocene or younger is inferred for the basalt flows and intrusive rocks of the Grays River area. Precise temporal equivalence to noncontiguous basalts of other areas is not implied, but approximate temporal equivalence to petrochemically similar basalts of the Columbia Plateau and western Oregon seems likely.

PALEOGEOLOGIC SETTING

The geologic maps of Oregon (Wells and Peck, 1961) and Washington (Huntting and others, 1961) show that the Miocene flows and intrusive rocks in the Grays River area are nearly continuous with the Columbia River Group of the Columbia Plateau, except in an area covered by younger rocks near Portland. However, the abundance of related intrusives in the Grays River area suggests proximity to an eruptive center; thus, the basalts of Three Tree Point and Altoona may never have been physically connected with basalt flows of the Columbia River Group to the east.

The predominantly massive character of the basalt of Three Tree Point indicates that the rock was extruded subaerially. The basalt of Altoona, on the other hand, is extensively brecciated and locally includes pillow lava; presumably it accumulated below sea level in the Grays River area. Complex mixing of sandstone and basalt breccia near the lower contact of the basalt of Altoona may be the result of splaying of intrusive feeders at very shallow depths in wet unconsolidated sand or of disruption of the wet sand by an overriding flow.

The southern sill of basalt of Pack Sack type intrudes the Astoria Formation. Its brecciation and high glass content suggest that the intrusion occurred at relatively shallow depths. The northern sill, which intrudes unit B, is, however, holocrystalline and probably crystallized at significantly greater depths. West of the map area, basalts of Three Tree Point and Pack Sack types occur as thick, broadly folded, northwest-striking sills.

QUATERNARY DEPOSITS

Older alluvium.—Deposits as much as 100 feet thick of sand, silt, and gravel derived from the local sedimentary and volcanic rocks are mapped as older alluvium (Wolfe and McKee, 1968) where they are terrace remnants along the edges of the Grays River valley. The broad flat upper surfaces of the terraces are easily recognized on aerial photographs.

Alluvium.—Holocene alluvium consisting of sand, silt, and gravel derived from local sources fills the major stream valleys. In the valleys of Salmon Creek and the Naselle River, this unit also includes some alluvium possibly as old as Pleistocene, as well as deposits produced by mass movement on valley walls.

Landslide debris.—Mass movement, from surface creep to landslides covering areas as wide as half a mile, is ubiquitous. Only the largest landslides, easily recognizable on aerial photographs, are shown on the map (Wolfe and McKee, 1968).

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